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HIGHWAY ROCK SLOPE MANAGEMENT PROGRAM





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Highway Rock Slope Management Program

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**Kentucky Transportation Center
College of Engineering
University of Kentucky**

**in cooperation with the
Kentucky Transportation Cabinet
The Commonwealth of Kentucky
and
Federal Highway Administration**

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February 2003

Mr. Jose Sepulveda
Division Administrator
Federal Highway Administration
330 West Broadway, Frankfort, Kentucky 40602-0536

SUBJECT: Implementation Statement: Final Report
Research Study KYSPR-98-177, "Highway Rock Slope Management Program"
Research Report KTC-03-06/SPR-177-98-1F

Dear Mr. Sepulveda:

Most highways in Kentucky are generally more than four decades old, and as they continue to age, highway rock cut slopes and embankments deteriorate and frequently collapse. Many factors cause rock falls. One well-known cause includes differential erosion that removes support for overlying rock layers and creates tension cracks. Another cause includes the gradual intrusion of water into the rock cut slope, which causes freezing and thawing cycles that creates cracks in the rock layers and loosens surface materials. Several years ago, rock slopes were constructed using a template design for benching with no consideration given to different types of rock units. This practice causes differential erosion between layers of hard and soft rock and leads to slope instability. Joints or vertical cracks in rock layers also contribute to rock falls. Highway rock slopes which have been exposed to many cycles of freezing and thawing, extreme differences in temperature, and natural chemical reactions weather over time and frequently produce rock falls that are hazards to the traveling public.

Engineers of the Kentucky Transportation Cabinet identified maintenance of highway rock slopes as a major engineering problem that involves considerable expenditures (millions of dollars) of funds each year. The Federal Highway Administration (FHWA) has strongly suggested to all states that a rock slope inventory be developed and maintained which includes corrective costs. Such information could be used to inform the United States Congress for potential funding and to create a program similar to the Bridge Replacement Program. The rock slope inventory was performed concurrently with an inventory of highway landslides. This report, the inventory of rock slopes performed on Kentucky's highways and described herein, and the development of a database of rock slope information are in response to the suggestion by FHWA. These efforts represent the first major step in attempting to correct rock fall problems in Kentucky. To develop an effective management plan requires identifying and developing information of rock fall sites where future corrections and reconstructions may be needed to improve safety and to maintain, or increase, the traffic capacities of roadways. A similar effort is underway for landslides.

Prior to this study, the actual numbers of potentially hazardous rock slopes existing on highways under the jurisdiction of the Kentucky Transportation Cabinet were unknown, but it was believed to be very sizeable. During the study period, more than 10,000 highway rock slopes were examined in an inventory of rock slopes in Kentucky. To date, approximately 2086 rock slopes of the 10,000 slopes were identified as potentially hazardous. Those sites were rated numerically and documented. The initial idea of performing an inventory of potentially hazardous rock slopes originated in a study conducted by the Geotechnology Section of the University of Kentucky Transportation Center. This study was funded directly by FHWA in

1988. Serious efforts to perform the inventory began in 1993 in a study sponsored by the Kentucky Transportation Cabinet and FHWA.

As a means of establishing a comprehensive system for managing the rock slope problems in Kentucky, a geotechnical database was developed and is described herein. Work on the rock slope portion of the database work began in about 1997 and was sponsored by the Kentucky Transportation Cabinet and FHWA. The database resides on a server of the Kentucky Transportation Cabinet. The computer program was developed in a windows' format and as a client-server application. Photographs and the latitudes and longitudes of all landslides and hazardous rock slopes were located using Global Positioning System (GPS) equipment--sub meter accuracy. All twelve Highway District Offices and several selected Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, authorized district and central office personnel can interact with the database. Personnel can easily recall and view the photographs in the database and the attributes of all landslides and rock slopes. Although the database contains several components, this report mainly focuses on the landslide and rock slope portions of the database. Other components of the database are under development and will be described at a later date. The landslide and rock fall segments of the geotechnical database establishes a priority program for allocating and funding the repairs of landslide and rock fall sites under the jurisdiction of the Kentucky Transportation Cabinet. Information in the database is being used in the development of the Cabinet's six-year plan.

The Kentucky Transportation Cabinet is also sponsoring additional research on the development of the geotechnical database. Second and third components of the geotechnical database are currently under development. The second portion includes the development of a landslide management program for storing the latitudes and longitudes, photographs, and attributes of highway landslides. The third component includes a program for storing the soil and rock data that is routinely generated by the Geotechnical Branch in their normal operations. Graphical user interfaces are under development for entering historical soil and rock data. Graphical user interfaces are being developed for "capturing" soil and rock data in a real-time mode, or as the data is generated.

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16. Abstract Development of a comprehensive geotechnical database for risk management of highway rock slope problems is described. Computer software selected to program the client/server application in windows' environment, components and structure of the geotechnical database, and some of the primary factors considered in constructing the database are discussed. In the establishment of a large database that will be used widely, it is extremely important to select development software that will allow simultaneous use of the database by numerous users. Major integrated components of the database include rock slope, landslide, and soil and rock engineering data. This report mainly focuses on the rock slope component. The rock slope database program provides procedures for gathering field data and rating the hazardous conditions of rock slopes. Secondary components of the database include statistical analyzers and engineering applications for performing "on-line" analysis of data, developing correlations between different soil parameters, and performing engineering analysis and designs. Procedures for entering historical soil and rock engineering data have been developed and programmed. Methods for "capturing" geotechnical data in a "real-time" mode, which will allow the storage of geotechnical data as it is generated, are currently being programmed. Issues concerning database security, engineering units, and storing and displaying maps, graphics, and photographs are discussed. The database contains procedures for dynamically overlaying the locations of landslides, rock slopes, and borings onto embedded roadway and digitized geological maps. Latitudes and longitudes of rock slopes and landslides were determined using Global Positioning System equipment (sub-meter accuracy). Strategies and illustrations of graphical user interfaces for data entry and retrieval are discussed. About 2086, potentially hazardous, rock slopes were rated numerically using the Rock Fall Hazard Rating system developed by the Oregon Department of Transportation and sponsored by the Federal Highway Administration (FHWA). A priority list of hazardous rock slopes can be generated rapidly.			
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EXECUTIVE SUMMARY

As highways in Kentucky continue to age, rock cut slopes and embankments deteriorate and frequently collapse. Highway rock slopes, which have been exposed to rain and snow, many cycles of freezing and thawing, extreme differences in temperature, and natural chemical reactions, weather over time and frequently produce rock falls that are hazards to the traveling public. The maintenance of highway slopes and the correction of landslides were identified by engineers of the Kentucky Transportation Cabinet as major engineering problems that involve considerable expenditures (millions of dollars) of funds each year. The Federal Highway Administration (FHWA) has strongly suggested to all states that a landslide and rock slope inventory be developed so cost estimates and, eventually, remedial plans may be developed.

The actual numbers of hazardous rock slopes and landslides existing on highways under the jurisdiction of the Kentucky Transportation Cabinet were unknown prior to these studies. Based on the data collected during studies sponsored by the Kentucky Transportation Cabinet, more than 10,000 highway rock slopes were examined in an inventory of rock slopes in Kentucky. To date, approximately 2,086 rock slopes of the 10,000 slopes were identified as potentially hazardous. Those rock slopes were rated numerically using the rock fall hazard rating system (RHRS) developed by the Oregon Department of Transportation (ODOT) and sponsored by the Federal Highway Administration and ten other states. The numerical ratings provide a priority list of sites where remedial, or mitigation, measures will be needed in the future. The main focus of this study and report was developing an inventory of potentially hazardous rock slopes on Kentucky's highways and a rock slope management system. An inventory and rating of landslide sites, which was performed concurrently, and development of a highway landslide management program have been documented elsewhere.

As a means of establishing a comprehensive system for managing rock slope problems in Kentucky, a geotechnical database was developed and is described herein. This database resides on a computer server of the Kentucky Transportation Cabinet. The computer program was developed as a client-server application in a Windows' format. The Kentucky geotechnical database was constructed using Oracle[®]8i (and 9i) database software. This database is the standard software used by the Kentucky Transportation Cabinet. PowerBuilder[®] software was used to build graphical user interfaces (GUI). The graphical user interfaces allow users to interact with the database stored on a production server of the Kentucky Transportation Cabinet. Rock slope attributes, including preliminary rating categories and numerical ratings, are stored in the database. Landslide attributes, including severity ratings devised by the University of Transportation Center and the Kentucky Transportation Cabinet, are stored in the database. Additionally, latitudes and longitudes of rock slopes and landslides, obtained from Global Positioning System (GPS) equipment (sub meter accuracy) and photographs are stored in the database.

All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, authorized district and central office personnel can interact with the database. Personnel can easily recall and view the photographs in the database and the attributes of all rock slopes and landslides. Although the database contains several components, this report mainly focuses on the rock slope portions of the database. The rock slope and landslide segments of the geotechnical database establish a priority program for allocating and funding repairs of rock fall and landslide sites that are the responsibility of the Kentucky Transportation Cabinet. Information in the database is

being used in the development of the Cabinet's six-year plan. By using MapObjects[®] software locations from GPS equipment, data site distribution can be viewed on different types of Kentucky maps. Any number of authorized users can log onto the database simultaneously from the twelve highway districts and central office locations. This feature is very useful since different users of the database located in different locations of the state can view the same data at the same time. For example, a user(s) in a central office(s) of Frankfort could view photographs of a rock slope, or landslide, while other users at different locations in the state can view the same photographs at the same time. While viewing the same site photographs at the same time, the users could discuss via telephone important remedial actions that may be needed at a site. Hence, this feature could decrease travel time of central office geotechnical engineering personnel, make better use of their geotechnical expertise, and increase their efficiency.

This report and the inventory of rock slopes performed on Kentucky's highways, and described herein, is a response to a suggestion by FHWA. These efforts represent the first major step in attempting to correct rock fall problems in Kentucky. To develop an effective management plan requires identifying and developing information of rock fall sites where future corrections and reconstruction may be needed to improve safety and to maintain, or, increase the traffic capacities of roadways. An inventory was performed using the ODOT rock fall hazard rating system of rock slope problem sites on all interstates, parkways, primary routes and several secondary routes in Kentucky.

General characteristics of rock slopes under the jurisdiction of the Kentucky Transportation Cabinet were identified. Grouping rock slopes into preliminary (subjective) categories, "A", "B", or "C" appears to be a reasonable approach. An "A" slope is considered by the rater to be potentially hazardous, while a "C" is considered to pose no danger. In placing a slope into a "B" category, the user is not sure about the potential danger of the slope. In analyzing the numerical ratings obtained from the RHR System, the rock slopes identified as "A" had a mean numerical score of 478. At one standard deviation, the scores ranged from 388 to 568. The mean score of the rock slope identified as "B" was 321 and at one standard deviation the score ranged from 224 to 418.

RHRS scores of "A" and "B" rock slopes in Kentucky ranged from a low of 69 to 689. The maximum score in the RHRS approach is 900. Numerical scores of "A" slopes ranged from 241 to 689. Scores of many of the rock slopes would probably have been increased if more detailed information regarding rock fall history had been available. The range for the "B" rated slopes was 69 to 562. The height of approximately 26 percent, or about 560 rock slopes, of the surveyed slopes ranged from 100 to 368 feet. As the height of slope increased the RHRS score increased. As the height of slope increases, the mitigation, or repair costs increase. The mean RHRS score of those slopes was 410. To prevent rock fall from entering the highway, sufficient space between the toe of the slope and the pavement, or "ditch effectiveness," must exist. In about 43 percent of the surveyed cases the "ditch effectiveness" was adequate to "good". However, in about 1 in 5 slopes, the ditch effectiveness was very "limited" to "no ditch". In those cases, potential traffic hazards exist, since any rock fall that may occur will land in the roadway. In about 1 in 4 slopes, the average vehicle risk, AVR, was significantly large and the chance that a vehicle may be hit by falling rock in those cases was very large. At about 1 in 3 slopes, the percent of decision sight distance was limited to very limited. Hence, at those sites, if rock falls onto the pavement, a driver would have very little response time to avoid hitting the roadway obstacle. In the RHRS scoring, the geology of a rock slope is scored in two different ways. In the first case, rock joints are scored while in the second case erosion of the rock formation is scored. The case receiving the largest score of the two cases is used in the total RHRS score. In 67 percent of the observed cases, rock jointing was scored higher. However, both factors were significant in causing rock fall.

The size of rock, or the volume of rock fall, that may reach the highway represents a significant danger to the traveling public. Generally, as the rock size, or volume, increases, the danger to motorists increases. The larger the size, or the volume of falling material, the greater opportunity for the falling rock to fill the ditch, or catchment area, and spill onto the highway. In about 60 percent of the observed cases, the block size was large and ranged from about 3 to 41 feet. In about 40 percent of the cases where the size of volume controlled the scoring, the size of volume ranged from about 9 to 24 ft³. When rock fall does occur, chances are large that the block size, or volume of rock, will be large and represent a danger to the traffic. Roadway width is another important parameter in the defining the rock fall character of a roadway system. As the width of highway increases, vehicular maneuverability increases and the chances of avoiding rock fall on the highway improve. However, in about 38 percent of the observed cases, the roadway score was large meaning that roadway width did not offer much maneuverability.

The rock fall history of rock slopes that were scored (by the ODOT RHRS) higher than about 500 was described as “Many” to “Constant”. For slopes scoring in the range of 300 to 500, the rock fall was described as “Occasional” to “Many”. When the RHRS score was less than 300, the rock fall history was described as mainly “Few” to “Occasional”.

In an attempt to establish a linkage between the RHRS score and rock fall history, it is strongly recommended that the Kentucky Geotechnical Database be fully implemented. This means that state personnel should start entering data into the system. When rock fall does occur at sites identified during this study, or new sites, the data should be entered describing the event, date, costs, and other important data pertaining to the event. By entering data each time an event occurs, this will aid in further identifying sites that pose dangers to the traveling public and help in establishing a priority list for future repairs. In essence, by entering data, the system can provide an effective means of managing rock slope and landslide problems. The RHRS scores of sites should be adjusted when more detailed rock fall histories are known.

Although there may not be an absolute link between rock fall history and RHRS score, experience to date indicates that there is some linkage. Three slopes that received the highest RHRS score (662 to 689) failed catastrophically shortly after they were rated. However, another rock slope that received a score of only 327 collapsed spilling rock debris onto two lanes of an interstate. Hence, entering rock fall events at each site by field personnel is essential to developing experience with the RHRS approach and improving the rating system in the future.

As shown by a limited number of examples cited herein, the cost of repairing, or applying mitigation measures, can be large. Remedial measures for a site may range from a few thousands of dollars to amounts exceeding several million dollars. Although the exact money needed to repair the large number of rock slopes identified herein and stored in the database is unknown at this time, the amount is believed to be very large and may well exceed 200 million dollars. The amount could be as large as 500 million dollars. At this stage, however, it is very difficult to affix exact amounts. Again these are very approximate estimates. Nevertheless, the amount of money needed in the future will probably require federal assistance in addressing these problems. Consequently, it is suggested that the Kentucky Transportation Cabinet may want to combine their efforts with other states in the nation to seek federal assistance in addressing these problems. It should be noted that some federal assistance is provided in reconstruction projects.

In summary, inventories of rock slope problems, as reported herein and building a windows database provide the first step toward developing an effective management plan to begin correcting rock slope problems in Kentucky. Field data describing attributes of each site and

hazardous, or severity, ratings have been collected. The data also includes photographs and latitudes and longitudes of each site. Priority listings of the more troublesome rock slope sites have been developed. To achieve maximum benefits of the management system, it is recommended that the rock slope and landslide portions of the database be fully implemented. This means that it is very desirable that district engineers and operations' engineers and personnel start entering essential data into the Kentucky Geotechnical Database. For instance, when a rock fall occurs at a site, field personnel need to enter this fact and include the cost of cleanup, any road closures, fatalities, or injuries, date of occurrence, and any other pertinent information. When any type of maintenance, or remedial mitigation, is performed at a site, this information should be added to the database. Similarly, when maintenance is performed at a landslide site, this information should be added to the database. For example, if rail piles have been added to the site, then this information, including costs and date of repairs should be added to the database. When a roadway is patched, the date and cost should be entered into the database. Patching a roadway in a landslide area more than 2 or 3 times may indicate that the landslide is continuing to move.

In addition to fully implementing the management systems built into the database, the next phase of addressing rock slope and landslide problems may involve development of preliminary plans so that cost estimates may be made. Basically, the first step in this process will involve obtaining cross sections of the slopes so that rock fall analyses may be performed. In estimating the type of remedial plan, or mitigation measure(s), to apply at a selected site, it is recommended that the Colorado Rock Fall Simulation program be used, when appropriate. In obtaining preliminary cross sections for performing the rock fall computer simulation calculations, it is recommended that new laser technology be considered. At least two approaches are available. In the first approach, a "laser" gun may be attached to a GPS unit and used to obtain an "open-face" geological log and profile of the rock slope. The user can usually position the laser gun and GPS unit at one location and point the laser at geological boundaries on the slope. A profile(s) of a slope may be obtained quickly using this approach. In certain instances, the profile may have to be obtained when foliage is not present. In the second approach, new 3-dimensional laser technology can be used to scan, or map, the entire slope in a reasonable time. After scanning, individual (2-dimensional) cross sections may be obtained for analysis. After obtaining a profile, the rock fall computer simulation runs would be performed to estimate the best remedial scheme and costs. Cross sections of the rock slope, computer results, and estimated repair methods and costs can be stored in the Kentucky Geotechnical Database for future reference. Considering the large numbers of potentially hazardous rock slopes and landslides identified in the inventories, and the large costs normally involved in repairing a single landslide, or rock slope problem, several millions of dollars will be required to correct those problems.

INTRODUCTION

Most highways in Kentucky are more than four decades old, and as they continue to age, highway cut slopes and embankments deteriorate and frequently collapse, as illustrated in Figures 1 and 2. Highway rock slopes, which have been exposed to rain and snow, many cycles



Figure 1. Massive rock fall on KY 1098 in Breathitt County



Figure 2. Highway embankment failure on KY 847 in Owsley County.

of freezing and thawing, extreme differences in temperature, and natural chemical reactions, weather over time and frequently produce rock falls that are hazards to the traveling public (Hopkins, Beckham, and Puckett 1996, Hopkins and Gilpin 1981, and Hopkins and Deen 1983). As noted by Bjerrum (1964), Skempton (1967), and Hopkins, et al 1988, many factors cause landslides. Well-known causes include the erosion of the toe of the embankments which removes support, the gradual intrusion of water into the embankment which increases forces tending to move the embankment downslide and a lowering of the available shear strength to resist the pull of gravity, and rapid drawdown of streams which occurs during flooding (Hopkins et al, 1975 and Hopkins, 1988). Embankments constructed more than four decades ago were oftentimes built at steep slope angles. Steep slopes promote the gradual reduction in the shear strength available to resist failure and cause instability. In many instances, past shale compaction specifications were inadequate to prevent excessive embankment settlement and instability, as illustrated in Figure 3, because of poor compaction (Hopkins and Gilpin, 1981; Hopkins and Deen, 1983; Hopkins 1988; and Hopkins and Beckham, 2000). Through research, many of the past inadequacies have been addressed and improved design and construction standards that emerged are used today in constructing new, or reconstructing older, highways. This has aided in decreasing the occurrence of the number of rock falls and landslides on new highways. However, only when new construction, or reconstruction, occurs can new design and construction techniques address the problems of aging embankments and rock slopes. Older highways, which suffer from inadequate design

and construction standards, will continue to present maintenance problems.

The maintenance of highway rock slopes and the correction of landslides were identified by engineers of the Kentucky Transportation Cabinet as major engineering problems that involve considerable expenditures (millions of dollars) of funds each year. The Federal Highway Administration (FHWA) has strongly suggested to all states that rock slope and landslide

inventories be developed so cost estimates and, eventually, remedial plans may be developed. Such information could be used to inform the United States Congress for potential funding and to create a program similar to the Bridge Replacement Program. The actual numbers of hazardous rock slopes and landslides existing on highways under the jurisdiction of the Kentucky Transportation Cabinet are unknown. But engineers believe the numbers are sizeable. This report and the inventories of rock slopes landslides performed on Kentucky's highways and described herein are in response to the suggestion by FHWA, Hopkins, et al (1988), Mathis¹, and Lutton (1977). The report represents an attempt to define the scope of highway rock slope problems in Kentucky on major routes. A companion report, which focuses on an inventory of

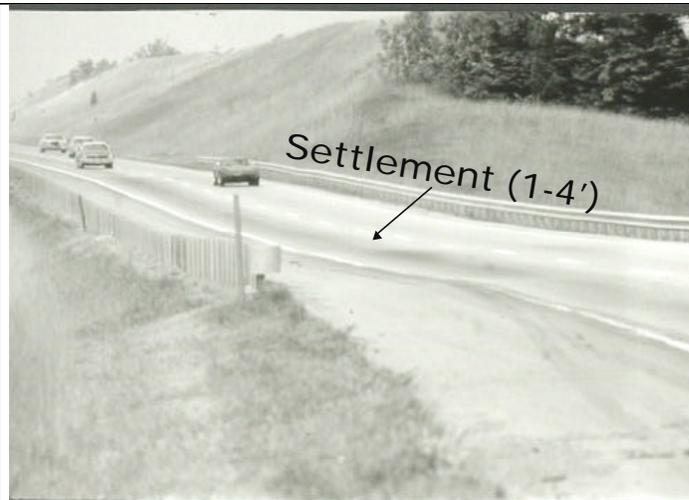


Figure 3. Example of large embankment settlement on I 75 about two decades after construction in Northern Kentucky (After Hopkins and Beckham, 1997, 1998).

highway landslides, has been documented elsewhere (Hopkins et al 2003). This report and the database provide actual numbers of potentially hazardous rock slopes on highways under the jurisdiction of the Kentucky Transportation Cabinet. These efforts represent the first major step in attempting to correct rock fall problems in Kentucky. To develop an effective management plan requires identifying and developing information of rock fall and landslide sites where future corrections and reconstruction may be needed to improve safety and to maintain, or increase the traffic capacities of roadways.

In planning, reconstructing, or maintaining, highways, knowledge of the occurrences and types of rock falls and landslides and engineering properties of soils and rocks in an area are essential to optimize design and minimize costs. From past experience, the cost of excavating and placing soil and rock is some ninety percent of the total cost of constructing a new highway in mountainous country. In flat to rolling terrain, the cost is some fifty percent of the total cost. The performance of a highway is directly related to types of soil and rock located in the highway corridor. Slope geometry selected for embankments and cuts in mountainous country largely affect both initial and future maintenance costs of the highway. Stabilities of embankment slopes and rock cuts are dependent on strength properties and weathering characteristics of the geological (rock and soil) units. Strengths of compacted soils and rocks greatly control the slope angles of embankments. Both cut and embankment slope angles dictate right-of-way requirements. The engineering properties of the materials used in the embankment subgrade have a large affect on the performance of the pavement. Excessive settlement, failure of the embankment, or a weak subgrade can cause premature failure of the pavement. Uneven pavements can cause traffic safety problems. Consequently, in planning highway facilities, first-hand knowledge of geotechnical information of the soil and rock units of an area during the design phase is invaluable. Moreover, knowledge of past performances of soil and geological units in rock cut slopes and embankments can aid in

¹ Private communication, former geotechnical engineer and Branch Manager of the Geotechnical Branch, Division of Materials, Kentucky Transportation Cabinet, Frankfort, Kentucky.

reducing failures. The number of past embankment and cut-slope failures in a region alerts the designer of potential design problems.

OBJECTIVES AND SCOPE

The major objective of this study was the establishment of a comprehensive system for managing rock slope problems in Kentucky. To accomplish this objective, two major steps had to be completed. As a means of managing efficiently a massive amount of information, a geotechnical database was developed and is described herein. The database resides on a server of the Kentucky Transportation Cabinet. The computer program was developed in a window format and as a client-server application. Numerous computer graphical user interface (GUI) screens were programmed for entering and retrieving landslide and rock slope information. The Geotechnical database contains three or four major components: landslide, rock slope, structures, and soil and rock information. Secondary components include engineering and statistical applications. Although the database contains several components, this report mainly focuses on the landslide and rock slope portions of the database.

The second important step of this study consisted of surveying thousands of highway rock slopes (and landslides) in Kentucky's highways. Photographs and the latitudes and longitudes of all hazardous rock slopes and landslides were obtained using Global Positioning System (GPS) equipment—sub-meter accuracy. All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, authorized district and central office personnel can interact with the database. Personnel can easily recall and view the photographs in the database and the attributes of all landslides and rock slopes. Other components of the database are under development and will be described at a later date. The landslide and rock fall modules of the geotechnical database establishes a priority program for allocating and funding the repairs of landslide and rock fall sites under the jurisdiction of the Kentucky Transportation Cabinet. Information in the database is used in the development of the Cabinet's six-year plan.

The Kentucky Transportation Cabinet is also sponsoring additional research on the development of the geotechnical database. A third component of the geotechnical database is currently under development. This major component involves storing the soil and rock data that are routinely generated by the Geotechnical Branch in their normal operations. Graphical user interfaces are under development for entering historical soil and rock data. As much data as practical are being entered during the study period. Graphical user interfaces are being developed for "capturing" soil and rock data in a real-time mode, or as the data is generated. This work will be reported at a later date. Rock slope and landslide inventories and database work began in 1993. This report, a report published in 1996 (Hopkins et al.) and two additional, pending companion reports are a culmination of this work.

DEVELOPMENT TOOLS

Where wide interest in stored information may exist, numerous users may want to access the data at the same time. Hence, the database software must contain a feature to permit this type of

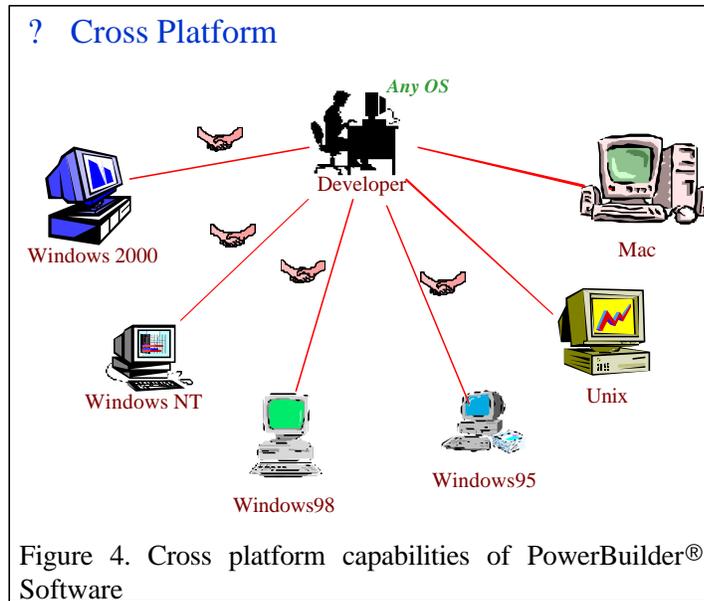


Figure 4. Cross platform capabilities of PowerBuilder® Software

accessibility. In anticipating this need, the Kentucky geotechnical database was constructed using Oracle®8i (and 9i) database software (Aronoff et al, 1997; Devraj, 2000; and Gruber, 2000). PowerBuilder® software (Sybase, 1999a, b, c), a product of SYBASE®, was used to build graphical user interfaces (GUI). This software is an object-oriented, development tool that allows the user to build powerful, multi-tier applications that can run on multiple platforms and interact with various databases, as illustrated in Figure 4. It provides the necessary tools to develop client/server applications and provides strong support for development in DataWindows and graphical user interface environment. The Data window, Figure 5, is a powerful tool for building graphical user interfaces.

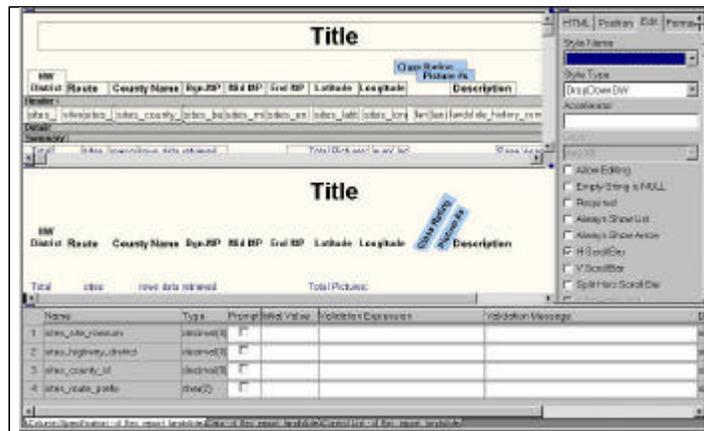


Figure 5. Data Window of PowerBuilder® 8.0.

The database can accommodate any number of “user hits” at essentially the same time. One example of the usefulness of this feature is illustrated in Figure 6. In this example, personnel located at district offices and geotechnical personnel in the central office can view the same data and

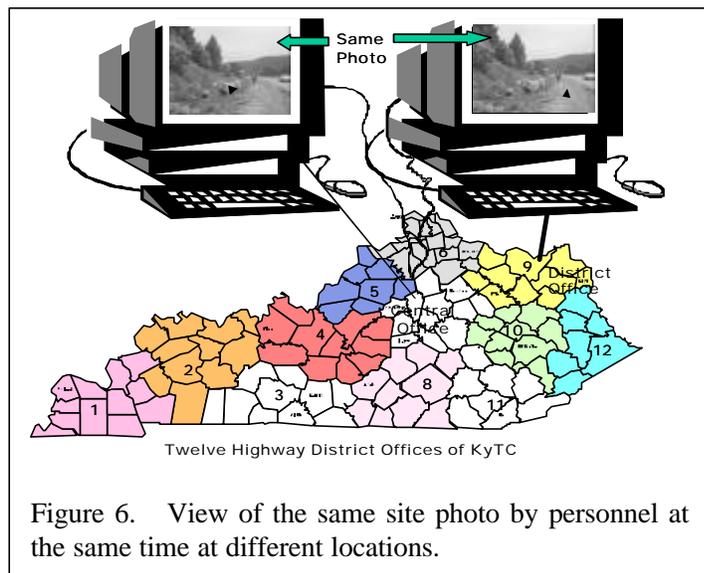


Figure 6. View of the same site photo by personnel at the same time at different locations.

photographs stored in the database of the same site at the same time and discuss (by telephone) the attributes of the site. Hence, this feature provides a quick means of assessing a situation before traveling to the site.

By using MapObjects® software (ESRI, 1999a, b)--a Geographical Information System (GIS) product of the Environmental Systems Research Institute, Inc. (ESRI®)--and locations from GPS equipment, data site distribution can be viewed on different types of Kentucky maps. MapObjects® consists of a set of mapping software components that allows maps to be

included with user applications. It comprises an ActiveX control (OCX) called the Map control and a set of over forty-five ActiveX Automation objects. Programs built with MapObjects® will display a map with multiple GIS map layers, such as roads, landslides, rock fall sites, geotechnical borings, streams, and boundaries. Features can be selected with an SQL expression and real-time or time-series data can be displayed dynamically. Embedding MapObjects® in PowerBuilder® applications provides both powerful map and data processing functions, which were instrumental in developing a successful application. Digitized 7.5-minute geologic quadrangles, produced by the Kentucky Geological Survey, can be stored on a local computer, and displayed with the databases. Other embedded maps include county roadway maps. Electronic photographs are stored as a JPEG (Joint Photographic Experts Group) file.

LOCATION OF SITES

Conventional Schemes of Locating Sites

The essential meaning of the prefix “geo” refers to specific properties of the planet earth and location is one of those properties. In the early development of the geotechnical database, it was recognized that the ability to physically locate the various geotechnical sites and data entries of associated attributes in the database was of paramount importance. Without the means of identifying the exact location on the earth of a boring or other highway feature limits the usefulness of geotechnical data in the database. Moreover, it was also realized that the ability to view these locations in relation to each other was also valuable. Each variable and its assigned properties had to be assigned a position on the earth whether numerical or textual to allow comparison to like variables and to allow navigation to the variables. Physically locating a site in the field using conventional schemes, such as surveying, is very difficult and time consuming.

For example, when a highway project is initially constructed, station numbers are used to identify the different locations of the boreholes, embankments, slopes, culverts, bridges, and other essential features of the project. During construction, stakes driven into the ground at fixed intervals, or station numbers, of length, identifies locations of the various features of the project. Hence, if a particular soil boring shown on a plan at a certain station number needs to be identified in the field, then that particular hole could be located physically by finding the stake with the proper station number. Unfortunately, station numbers (stakes) are destroyed during and after construction and do not provide a means of identifying a particular location after construction. The stakes are only used during construction and are temporary because they are made of wood and rot after some time. Moreover, the station numbers of numerous past highway projects are frequently not tied to a fixed and accurate point on the earth. To locate a highway feature after construction using standard surveying techniques would be too costly and generally impractical.

Consequently, a system evolved for identifying locations of highway features in the field by assigning a particular location to a county name, the highway (route) number, and the mile point. Using this conventional system, which is only approximate, allows engineers to physically locate in a fairly reasonable manner a highway feature in the field. It also allows a rough estimate of comparison of locations from a map. Because this system continues to be used today by operation engineers and others, this method of identifying and referring to a location of a highway feature was retained in building the geotechnical database.

Although identifying a location by county number, route number, and milepost has provided a fair means of identifying a highway feature in the field, this system is oftentimes inaccurate for a



Figure 7. After reconstruction, US 23 in Johnson and Floyd Counties was renumbered KY 321 in the mid-nineties.

number of reasons. First, odometers on different vehicles are not accurate to the tenth of a mile. Different vehicles may yield different locations, although they may began at the same location, they may yield different locations. Secondly, reconstruction of new highways in Kentucky very often results in a change in mile points. Generally, reconstruction tends to shorten an old road and change existing mile points. Sometimes the highway route number itself changes, as illustrated in Figure 7, and the locations become virtually useless. The conventional system that is widely used for defining a location by county number, route number, and

mile point is not unique because the identifiers of that location are subject to change in the future. Because of the nature of these possible errors, a system was needed to provide a unique means of identifying highway sites, or features. Some geotechnical data such as borings could not be referenced to the mile point system and were lost.

Application of the Global Positioning System (GPS) for Locating Sites

To overcome difficulties associated with the mile point system and conventional surveying, and beginning in 1998, Global Positioning System (GPS) equipment was acquired and used to locate hazardous rock fall sites and landslides along Kentucky's highways. The GPS system provides an excellent way of identifying a highway feature by latitude and longitude, which are unique numbers. This equipment produces accurate coordinates that do not change as the arterial highway system changes in Kentucky.

The unit first used to locate sites in Kentucky was Trimble's ProXR mapping grade system. This unit provides a location accuracy of one-meter (or sub-meter) horizontal and six meters vertical. The unit is portable and can be carried as a pack (Figure 8), or mobile mounted in a vehicle, as shown in Figures 9 and 10, respectively. Set-up time is about five minutes and requires no permanent changes to the vehicle. The self-contained system consists of an antenna (Figure 9), receiver, and data logger (Figures 10). The Trimble ProXR antenna also allows real-time correction in the field with the use of a built-in radio antenna that receives signals from near-by beacons transmitting fixed correct coordinates. The unit also features multi-path rejection technology. As a pack unit, the ProXR is very concise. However, the large weight of the unit discouraged the use of the pack as a common practice. As a mobile mount, it can be separated for ease of use. The antenna uses a magnetic mount that holds fast to the top of any vehicle. While this system eliminated the problems with the mile point system, some minor problems arose, such as the weight problem and time required to learn the use of the system.

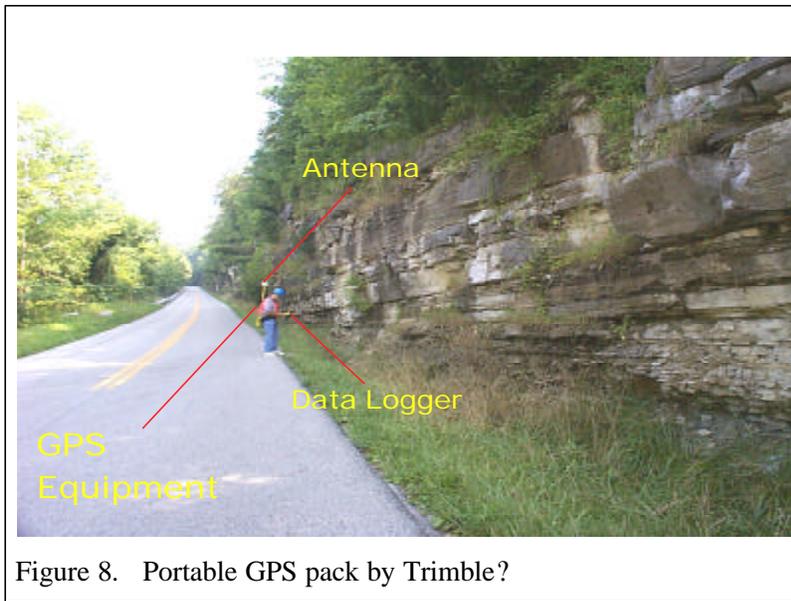


Figure 8. Portable GPS pack by Trimble?

The Global Positioning System operates by producing a pseudo random code and comparing it with the same code embedded in a radio signal transmitted by satellites orbiting the earth. In theory, these codes are produced at the same time. The time difference from the instant the receiver produced the code and the instant the code was received from the satellite is used to calculate distance. Signals from at least four satellites are needed to produce three-dimensional positions. There are 24 satellites that make

up a constellation in a non-geosynchronous orbit 12,600 miles above the earth. These satellites, called space vehicles by the GPS, are in constant contact with each other and continually upgrade the receiver's clock using onboard atomic clocks accurate to one ten millionth of a second.

A signal from the first satellite locates the position to a point on a sphere. A signal from the second satellite places the position at the intersection of two spheres. The signal from the third satellite narrows the position to one of two points made by a third intersecting sphere. The fourth



Figure 9. The Trimble? ProXR, vehicular-mounted antenna.

satellite locates the true point three dimensionally as the fourth sphere intersects the first three at the point. This process is known as satellite trilateration and is one of five principles of operation along with satellite ranging, accurate timing, satellite positioning, and correcting errors.

The calculations behind satellite ranging assume the signals travel at a constant speed--the speed of light. Because this is only a constant in a vacuum, errors are inherent and must be corrected. Upon striking the earth's atmosphere, the signal from the satellite must pass through the "D layer" of the atmosphere. When the atmosphere is

charged by solar rays, the radio signal is absorbed. It also passes the troposphere, which creates lag as well. The department of defense does correct clock and orbital errors having to do with timing and positioning. Multipath interference occurs when the signal is reflected off other objects such as buildings before reaching the receiver. The antenna on the ProXR detects and rejects such signals using advanced signal processing.



Figure 10. Data logger

Essentially, three methods are available for obtaining data using the ProXR. The first method consists of simply recording the position read in the field onto a data sheet. The second method requires logging a number of positions into a file (rover file), downloading these into a desktop computer program, and comparing them with positions (base files) taken by another receiver over a known point. If they are close enough together, they should “see” the same constellation of satellites and record the same error allowing the correction to be applied to your new field point. This is called “Differential Correction.” The third

method actually does this correction in the field by receiving a low-power AM signal from a nearby beacon. This is termed “Real Time Differential Correction.”

All rock fall and landslide sites have been located using the mapping-grade GPS equipment. This technology has also been used to map and define some highways, including bridges and culverts. This system provides a way to link the two methods of locating these structures together. Using a “data dictionary” in the data logger’s software, all the location data including, county, route and mile point can be entered and saved with the position record. The data logger is also able to record the date and time and name of the person using the equipment. Also it keeps an embedded record of what satellites it used to calculate the positions and the condition of the signal. These two items are termed an ephemeris and almanac. Upon returning to the office, all data are “dumped” (via serial port connection) into the desktop processing software where it is corrected, if needed, and all points are processed and averaged to give the most accurate location. The data can also be viewed or exported to a number of formats. The ProXR allows “real-time correction,” as well as differential correction. The receiver monitors for any beacon signal. The handheld data-logging unit stores all data taken by the receiver in a “Rover-File”. The unit is self-contained in an airtight hard-shell case, as shown in Figure 10. The Pathfinder software program is included with the unit and is used to process, view, and export positions taken by the ProXR. It also allows the manipulation of datum, projection, and units of display and is capable of plotting directly to a printer, as shown Figure 11.

After all data are corrected and ready for use, it is exported to an ASCII format and printed. At this point, all data concerning the site are available, as well as the site position. This printout is used by the person(s) inputting the site information into the geotechnical databank. After all positions are entered and stored on the databank, this printout is placed in a binder with the original field data sheets for future reference. The digital file is placed in a file according to highway district and backed up to a CD regularly along with the corrected data logged files. Exporting it to a GIS format and opening the data using a GIS program, such as ArcGIS, can make further use of the data. Using the measured field positions, the locations of rock fall, or landslide, sites can be placed on aerial photographs to obtain a better view of where the sites are in relation to their physical environment. From this information, picture files can be created and

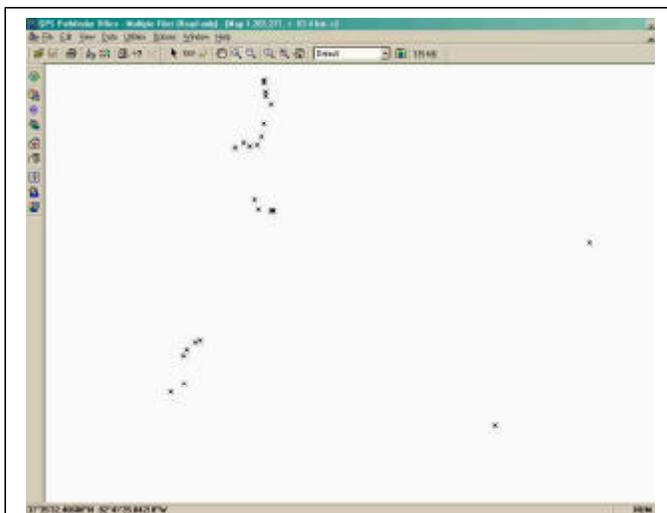


Figure 11. Plot of mapped positions.

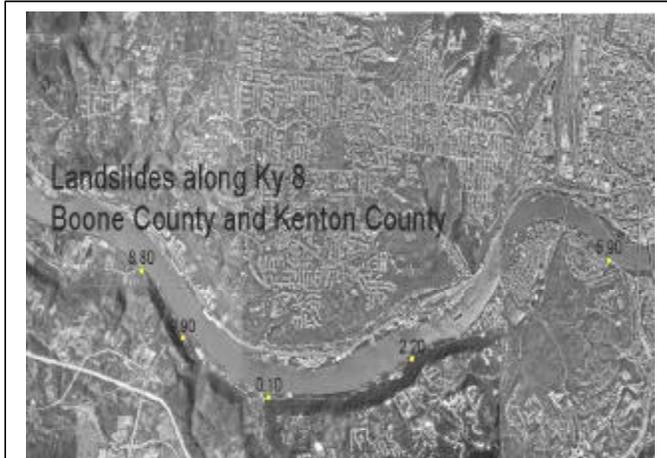


Figure 12. Locations of landslides superimposed on an aerial photograph along KY 9 in Boone and Kenton Counties, Kentucky.

placed with a specific site in the data bank. Viewing the sites on an aerial photograph may provide users an insight as to the cause of a problem or give a view of terrain that must be negotiated to get to a particular site.

To illustrate, the latitude and longitude of several landslide areas along KY route 9 have been plotted on an aerial photograph, figure 12, or an ortho-photo quarter quadrangle, of a particular stretch of the Ohio River. Apparently, the landslides are occurring in the bends of the river at this location that are most susceptible to erosion along the base of the embankments and natural slopes. Natural slopes in this area are composed of residual soils that were derived from the Kope Geological Formation. These soils and the Kope shales were used to construct the embankments of KY 9. The clay shales of the Kope Formation have been involved in numerous landslides of this area. As support of the slopes is lost, the embankments and natural slopes gradual “creep” down slope. Eventually, as the erosion and creep continue, and with the occurrence of rapid drawdown during flooding, the slopes fail. Viewing landslides in this manner can aid in determining the major causes of landslides in certain regions.

Conversion Between State Plane Coordinate System (SPCS) and Geodetic Position Latitude/Longitude

Terms and Definitions (Mitchell and Simmons 1977)

As with any plane-rectangular coordinate system, a projection employed in establishing a State coordinate system may be represented by two sets of parallel straight lines that are intersected by other parallel lines at right angles. The network thus formed is termed a grid. One set of these lines is parallel to the plane of a meridian passing approximately through the center of the area shown on the grid, and the grid line corresponding to that meridian is the Axis of Y of the grid. It is also termed the central meridian of the grid. Forming right angles with the Axis of Y and to the south of the area shown on the grid is the Axis of X. The point of intersection of these axes is the origin of coordinates. The position of a point represented on the grid can be defined by stating two distances, termed coordinates.

One of these distances, known as the x-coordinate, gives the position in an east-and-west direction. The other distance, known as the y-coordinate, gives the position in a north-and-south direction. The x-coordinates increase in size, numerically, from west to east; the y-coordinates increase in size from south to north. *All x-coordinates is an area represented on a State grid are made positive by assigning the origin the coordinates: $x = 0$ plus a large constant.* For any point, then, the x-coordinate equals the value of x adopted for the origin, plus or minus the distance of the point east or west from the central meridian (Axis of Y); and the y-coordinate equals the perpendicular distance to the point from the Axis of X. The linear unit of the State coordinate systems is the foot (equal to 12 inches) and it is defined by the equivalence: 1 international meter = 39.37 inches exactly.

The linear distance between two points on a State coordinate system, as obtained by computation or scaled from the grid, is termed the grid length of the line connecting those points. The angle between a line on the grid and the Axis of Y, reckoned clockwise from the south through 360°, is the grid azimuth of the line. The computations involved in obtaining a grid length and a grid azimuth from grid coordinates performed by means of the formulas of plane trigonometry.

Geodetic and Plane-Coordinate Positions (Mitchell and Simmons 1977)

For more than a century, the United States Coast and Geodetic survey has engaged in geodetic operations, which determined the geodetic positions – the latitudes and longitudes – of thousands of monument points distributed throughout the country. These latitudes and longitudes are on an ideal figure – a spheroid of reference, which closely approaches the sea-level surface of the Earth. By mathematical processes, the positions of the grid lines of a State coordinate system are determined with respect to the meridians and parallels on the spheroid of reference. A point that is defined by stating its latitude and longitude on the spheroid of reference may also be defined by stating its x- and y-coordinates on a State grid. If either position is known, the other can be derived by formal mathematical computation. So too with lengths and azimuths: the geodetic length and azimuths between two positions can be transformed into grid length and azimuth by mathematical operation. Or the process may be reversed when grid values are known and geodetic values are desired.

In general, any survey computations involving the use of geodetic position data can also be accomplished with the corresponding grid data; but with this difference: results obtained with geodetic data are exact, but they require the use of involved and tedious spherical formulas and special tables. On the other hand, results obtained with grid data are not exact, since they involve certain allowances that must be made in the transfer of survey data from the curved surface of the Earth (spheroid) to the plane surface of a State coordinate system; but the computations with the data are quite simple, *being made with the ordinary formulas of plane surveying; and with the State coordinate systems, exact correlation of grid values and geodetic values is readily obtained by simple mathematical procedures.*

State Grid Zones (Mitchell and Simmons 1977)

One of the important characteristics of the State coordinate systems is the small number of separate grids required to cover a State; or, to put it differently, the large area that is served by a single origin and reference meridian. Since the geodetic data determined by the national control survey - the latitudes and longitudes of points, and the lengths and azimuths of lines - are sea-level data, it follows that surveys which are to be adjusted to stations of the national survey must

first be reduced to a sea-level base. And as the State coordinate systems are developed directly from geodetic values, the use of those systems requires the further reduction of the sea-level values to grid values.

In reducing a ground-level length to its corresponding grid length on a State coordinate system, the two processes involved – reduction to sea level and thence to the grid – may, for most land surveys, be performed in a single operation, employing a factor which is a combination of the sea-level and scale factors.

SPCS 27 Background (Stem 1989)

The State Plane Coordinate System of 1927 (SPCS 27) was designed in the 1930s by the U.S. Coast and Geodetic Survey (predecessor of the National Ocean Service) to enable surveyors, mapmakers, and engineers to connect their land or engineering surveys to a common reference system, the North American Datum of 1927. The following criteria were applied in the design of the State Plane Coordinate System of 1927:

- ?? Use of conformal mapping projection.
- ?? Restricting the maximum distortion to less than one part in 10,000.
- ?? Covering an entire State with as few zones of a projection as possible.
- ?? Defining boundaries of projection zones as an aggregation of counties.

It is impossible to map a curved Earth on a flat map using plane coordinates without distorting angles, azimuths, distances, or area. It is possible to design a map such that some of the four remain undistorted by selecting an appropriate “map projection”. A map projection in which angles on the curved Earth are preserved after being projected to a plane is called a “conformal” projection. Three conformal map projections were used in designing the original State plane coordinate system: the Lambert conformal conic projection, the transverse Mercator projection, and the oblique Mercator projection. The Lambert projection was used for States that are long in the east-west direction (e.g., Kentucky, Tennessee, North Carolina), or for States that prefer to be divided into several zones of east-west extent. The transverse Mercator projection was used for States (or zones within States) that are long in the north-south direction (e.g., Vermont and Indiana), and the oblique Mercator was used in one zone of Alaska when neither of these two was appropriate. These same map projections are also often custom designed to provide a coordinate system for a local or regional project.

Land survey distance measurements in the 1930s were typically made with a steel tape, or something less precise. Accuracy rarely exceeded one part in 10,000. Therefore, the designers of SPCS 27 concluded that a maximum systematic distance scale distortion attributed to the projection of 1:10,000 could be absorbed in the computations without adverse impact on the survey. If distances were more accurate than 1:10,000, or if the systematic scale distortion could not be tolerated, the effect of scale distortion could be eliminated by computing and applying an appropriate grid scale factor correction. Admittedly, the one in 10,000 limit was set at an arbitrary level, but it worked well for its intended purpose and was not restrictive on the quality of the survey when grid scale factor was computed and applied.

To keep the scale distortion at less than one part in 10,000 when designing the SPCS 27, some States required multiple projection “zones”. Thus some States have only one State plane coordinate zone, some have two or three zones, and the State of Alaska has 10 zones that incorporate all three projections. With the exception of Alaska, the zone boundaries in each State

followed county boundaries. There was usually sufficient overlap from one zone to another to accommodate projects or surveys that crossed zone boundaries and still limit the scale distortion to 1:10,000. In more recent years, survey accuracy usually exceeds 1:10,000. More surveyors became accustomed to correcting distance observations for projection scale distortion by applying the grid scale factor correction. When the correction is used, zone boundaries become less important, as projects may extend farther into an adjacent zone.

Requirement for SPCS 83 and SPCS 27 (Stem 1989)

The necessity for the State Plane Coordinate System of 1983 (SPCS 83) arose from the establishment of the North American Datum of 1983 (NAD 83). When NAD 27 was readjusted and redefined by the National Geodetic Survey, a project that began in 1975 and finished in 1986, SPCS 27 became obsolete. NAD 83 produced new geodetic coordinates for all horizontal control points in the National Geodetic Reference System (NGRS). The project was undertaken because NAD 27 values could no longer provide the quality of horizontal control required by surveyors and engineers without regional recomputations (least squares adjustments) to repair the existing network. NAD 83 supplied the following improvements:

- ?? One hundred and fifty years of geodetic observations (approximately 1.8 million) were adjusted simultaneously, eliminating error propagation, which occurs when projects must be mathematically assembled on a “piecemeal” basis.
- ?? The precise transcontinental traverse, satellite triangulation, Doppler position, baselines established by electronic distance measurements (EDM), and baselines established by very long baseline interferometry (VLBI), improved the internal consistency of the network.
- ?? A new figure of the Earth, the Geodetic Reference System of 1980 (GRS 80), which approximates the Earth’s true size and shape, supplied a better fit than the Clarke 1866 spheroid, the reference surface used with NAD 27.
- ?? The origin or the datum was moved from station MEADES RANCH in Kansas to the Earth’s center of mass, for compatibility with satellite systems.

Not only will the published geodetic position of each control point change, but also the State plane coordinates will change for the following reasons:

- ?? The plane coordinates are mathematically derived (using “mapping equations”) from geodetic coordinates.
- ?? The new figure of the Earth, the GRS 80 ellipsoid, has different values for the semi major axis “a” and flattening “f” (and eccentricity “e” and semi minor axis “b”). These ellipsoidal parameters are often embedded in the mapping equations and their change produces different plane coordinates.
- ?? The mapping equations are accurate to the millimeter, whereas previous equations promulgated by NGS were derivatives of logarithmic calculations with generally accepted approximations.
- ?? The States have defined the defining constants of several zones.
- ?? The numeric grid value of the origin of each zone has been significantly changed to make the coordinates appear clearly different.
- ?? The State plane coordinates for all points published on NAD 83 by NGS will be in metric units.

?? The NPCS 83 uses the Gauss-Kruger form of the transverse Mercator projection, whereas the SPCS 27 used the Gauss-Schreiber form of the equations.

SPCS 83 Design (Stem 1989)

In the mid-1970s NGS considered several alternatives to SPCS 83. Some geodesists advocated retaining the design of the existing State plane coordinate system (projection type, boundaries, and defining constants) and others believed that a system based on a single projection type should be adopted. The single projection proponents contended that the present SPCS was cumbersome, since three projections involving 127 zones were employed.

Studies were instituted to decide whether a single system would meet the principal requirements better than SPCS 27 and the transverse Mercator projection with zone of 2° in width. Throughout these studies, three dominant factors for retaining the SPCS 27 design were evident: SPCS had been accepted by legislative action in 37 States. The grids had been in use for more than 40 years and most surveyors and engineers were familiar with the definition and procedures involved in using them. Except for academic and puristic considerations the philosophy of SPCS 27 was fundamentally sound. With availability of electronic calculators and computers, little merit was found in reducing the number of zones or projection type. There was merit in minimizing the number of changes to SPCS legislation. For these reasons a decision was made to retain the basic design philosophy of SPCS 27 in SPCS 83.

The above decision was expanded to enable NGS to also publish UTM coordinates for those users who preferred that system. Both grids are now fully supported by NGS for surveying and mapping purposes. It is recognized that requirements will arise when additional projections may be required, and there is no reason to limit use to only the SPCS 83 and UTM system.

Polynomial Formulas and Coefficients for the Lambert Projection (Stem 1989)

Conversion of coordinates from NAD 83 geodetic positions to SPCS 83 plane coordinate positions, and vice versa, can be greatly simplified for the Lambert projection using precomputed zone constants obtained by polynomial curve fitting. NGS developed the Lambert “polynomial coefficient” approach as an alternative to the rigorous mapping equations. For many zones the solution of the textbook mapping equations for the Lambert projection requires the use of more than 10 significant digits to obtain millimeter accuracy, and in light of the programmable calculators generally in use by surveyors/engineers, an alternative approach was warranted. The mapping equations of the transverse Mercator projection do not present the same numerical problem as does the Lambert projection. Therefore, 10 significant digits are adequate. For the polynomial coefficient method of the Lambert projection, 10 significant digits will produce millimeter accuracy in all zones.

Given the precomputed polynomial coefficients, the conversion process by this method reduces to the solution of simple algebraic equations, requiring no exponential or logarithmic functions. It is therefore very efficient for hand calculators and small computers. In addition, the conversion is not too difficult to apply manually without the aid of programming. For this reason, the polynomial coefficient approach has also been listed as a manual approach in table form. When programmed, this approach may be more efficient than mapping equations.

The fundamental polynomial equations of this method are

$$u = L_1 ?? + L_2 ??^2 + L_3 ??^? + L_4 ??^? ?? L_5 ??^????????????????????(forward conversion) \tag{1}$$

$$l = l_0 + G_1 u + G_2 u^2 + G_3 u^3 + G_4 u^4 + G_5 u^5 \quad (\text{inverse conversion}) \quad (2)$$

From the equations and Figure 13, “u” is a distance on the mapping radius “R” between the central parallel and a given point. The determination of “u” in meters on a plane by a polynomial, given point (l, b) in the forward conversion, and the determination by a polynomial of l in radians on the ellipsoid given point (N, E) in the inverse conversion, is the unique aspect of this method. The L_i coefficients perform the functions: (1) computing the length of the meridian arc between l and l₀, and (2) converting that length to (R₀ - R) which is its equivalent on the mapping radius. The coefficients, G_i, serve the same two-stage process, but in reverse. The polynomial coefficients of these equations, L_i and G_i, were separately determined by a least squares curve-fitting program that also provided information as to the accuracy of the fit. Ten data points were used for Lambert zones that provided 0.5 mm coordinate accuracy in the conversion. Kentucky zones required only four coefficients for each forward and inverse conversion, four L’s and four G’s.

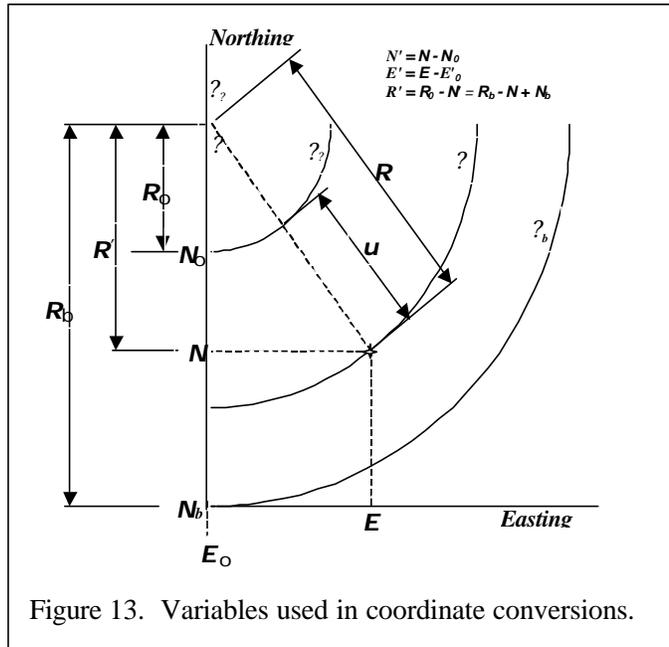


Figure 13. Variables used in coordinate conversions.

Direct Conversion Computation for SPCS 83(Stem 1989)

The computation starts with the geodetic position of a point (l, b), and computes the Lambert grid coordinates (N, E), convergence angle (γ), and grid scale factor (k).

$$l = l_0 + L_1 \Delta l + L_2 \Delta l^2 + L_3 \Delta l^3 + L_4 \Delta l^4 + L_5 \Delta l^5 \quad (\Delta l \text{ in decimal degrees}) \quad (3)$$

$$u = L_1 \Delta l + L_2 \Delta l^2 + L_3 \Delta l^3 + L_4 \Delta l^4 + L_5 \Delta l^5$$

In Kentucky, only four L’s are required. After changing to nested form, the above formula becomes

$$u = \Delta l (L_1 + \Delta l (L_2 + \Delta l (L_3 + L_4 \Delta l)))$$

$$R = R_0 - u$$

$$\gamma = (\gamma_0 - \Delta l \sin(\gamma_0)) \quad \text{convergence angle}$$

$$E' = R \sin \gamma$$

$$N' = u + E' \tan(\gamma/2)$$

$$E = E' + E_0 \quad \text{easting}$$

$$N = N' + N_0 \quad \text{northing}$$

$$k = F_1 + F_2 u^2 + F_3 u^3 \quad \text{grid scale factor}$$

Inverse Conversion Computation for SPCS 83 (Stem 1989)

The computation starts with the Lambert coordinates (N, E) from which are computed the geodetic coordinates (ϕ , λ), convergence angle (α), and grid scale factor(k).

$$N' = N - N_0$$

$$E' = E - E_0$$

$$R' = R_0 - N'$$

$$\alpha = \tan^{-1}(E'/R') \quad \text{convergence angle}$$

$$\lambda = \lambda_0 - \alpha / \sin(\phi_0) \quad \text{longitude}$$

$$u = N' - E' \tan(\alpha/2)$$

$$k = k_0 - \alpha = G_1 u + G_2 u^2 + G_3 u^3 + G_4 u^4 + G_5 u^5 \quad (\alpha \text{ in decimal degrees})$$

In Kentucky, only four G's are required. After changing to nested form, the above formula becomes

$$k = u(G_1 + u(G_2 + u(G_3 + G_4 u)))$$

$$\phi = \phi_0 + \alpha \quad \text{latitude}$$

$$k = F_1 + F_2 u^2 + F_3 u^3 \quad \text{grid scale factor in Figure 13 and formulas,}$$

where

ϕ Parallel of geodetic latitude, positive north

ϕ_0 Central parallel, the latitude of the true projection origin

ϕ_b Latitude of the grid origin

λ Meridian of geodetic longitude, positive west

λ_0 Central meridian, longitude of the true and grid origin

k Grid scale factor at a general point

α Convergence angle

N Northing coordinate

N_b The northing value for ϕ_b at the central meridian (the grid origin).
Sometimes identified as the false northing

N_0 Northing value at the intersection of the central meridian with the central parallel (the true projection origin)

E Easting coordinate

E_0 The easting value at the central meridian λ_0 . Sometimes identified as the false easting

R Mapping radius at latitude ϕ

R_b Mapping radius at latitude ϕ_b

R_0 Mapping radius at latitude ϕ_0

L_i Coefficients used in the forward conversion process

G_i Coefficients used in the inverse conversion process

F_i Coefficients used for grid scale factor

Constants for Lambert Projection in SPCS 83(Stem 1989)

In the Kentucky North, Zone # 1601, numerical values are as follows:

$$\begin{aligned}
\phi_0 &= 38.4672539691 \\
\phi_0 &= 84.25 \\
E_0 &= 500000. \\
N_0 &= 107362.4795 \\
R_0 &= 8037943.9917 \\
L_1 &= 111001.1272 \\
L_2 &= 9.49969 \\
L_3 &= 5.63960 \\
L_4 &= 0.019624 \\
G_1 &= 9.008917501E-06 \\
G_2 &= -6.94594E-15 \\
G_3 &= -3.71303E-20 \\
G_4 &= -1.0140E-27 \\
F_1 &= 0.999962079530 \\
F_2 &= 1.23109E-14 \\
F_3 &= 5.03E-22
\end{aligned}$$

In the Kentucky South, Zone # 1602, numerical values are as follows:

$$\begin{aligned}
\phi_0 &= 37.3341456532 \\
\phi_0 &= 84.75 \\
E_0 &= 500000. \\
N_0 &= 611064.2249 \\
R_0 &= 8372015.2303 \\
L_1 &= 110977.8556 \\
L_2 &= 9.40195 \\
L_3 &= 5.64201 \\
L_4 &= 0.018759 \\
G_1 &= 9.010806634E-06 \\
G_2 &= -6.87874E-15 \\
G_3 &= -3.71775E-20 \\
G_4 &= -9.7208E-28 \\
F_1 &= 0.999945401603 \\
F_2 &= 1.23142E-14 \\
F_3 &= 4.82E-22
\end{aligned}$$

Direct Conversion Computation for SPCS 27 (Claire 1968)

The computation starts with the geodetic position of point (ϕ , λ), and computes the Lambert grid coordinates (x , y), convergence angle (α), and grid scale factor(k).

$$s = 101.2794065 (60 (L_7 - \phi') + L_8 - \phi'') + (1052.893882 - (4.483344 - 0.023520 \cos^2 \phi) \cos^2 \phi) \sin \phi \cos \phi$$

where ϕ' is in degrees and minutes of ϕ expressed in whole minutes, ϕ'' is the remainder of ϕ in seconds, and

$$R = L_3 + sL_5(1 + (s/10^8)^2 (L_9 - (s/10^8) L_{10} + (s/10^8)^2 L_{11}))$$

$$? = L_6(L_2 - ?) \quad (? \text{ and } ? \text{ are in seconds, } ? \text{ is convergence})$$

$$x = L_1 + R \sin ??$$

$$y = L_4 - R + 2R \sin^2(? / 2)$$

$$?? = L_6R(1 - 0.0067686580 \sin^2?)^{1/2} / (20925832.16 \cos ?). \quad (\text{Scale factor})$$

Inverse Conversion Computation for SPCS 27 (Claire 1968)

The computation starts with the Lambert coordinates (x, y) from which are computed the geodetic coordinates (? , ?).

$$? = \arctan((x - L_1) / (L_4 - y))$$

$$? = L_2 - ? / L_6 \quad (? \text{ and } ? \text{ are in seconds})$$

$$R = (L_4 - y) / \cos ??$$

$$s_1 = (L_4 - L_3 - y + 2 R \sin^2(? / 2)) / L_5$$

$$s_2 = s_1 / (1 + (s_1 / 10^8)^2 L_9 - (s_1 / 10^8)^3 L_{10} + (s_1 / 10^8)^4 L_{11})$$

$$s_3 = s_1 / (1 + (s_2 / 10^8)^2 L_9 - (s_2 / 10^8)^3 L_{10} + (s_2 / 10^8)^4 L_{11})$$

$$s = s_1 / (1 + (s_3 / 10^8)^2 L_9 - (s_3 / 10^8)^3 L_{10} + (s_3 / 10^8)^4 L_{11})$$

$$? ' = L_7 - 600 \quad (\text{degrees and minutes of } ? \text{ in whole minutes})$$

$$? '' = 36000 + L_8 - 0.009873675553 s \quad (\text{remainder of } ? \text{ in seconds})$$

$$? = ? ' + ? ''$$

$$? ' = L_7 - 600 \quad (\text{degrees and minutes of } ? \text{ in whole minutes})$$

$$? '' = ? '' + (1047.546710 + (6.192760 + 0.050912 \cos^2??) \cos^2??) \sin? \cos? \quad (\text{remainder of } ? \text{ in seconds})$$

$$? = ? ' + ? ''$$

Constants for Lambert Projection in SPCS 27(Claire 1968)

In the Kentucky North, Zone # 1601, values are as follows:

- L₁ = 2,000,000.000
- L₂ = 303,300.00
- L₃ = 26,371,820.68
- L₄ = 26,724,051.82
- L₅ = 0.999962081
- L₆ = 0.6220672671
- L₇ = 2299
- L₈ = 30.63364
- L₉ = 3.81202
- L₁₀ = 3.62113
- L₁₁ = 0

In the Kentucky South, Zone # 1602, values are as follows:

- L₁ = 2,000,000.000
- L₂ = 328,700.00
- L₃ = 27,467,860.75

- L₄ = 27,832,235.64
- L₅ = 0.9999453808
- L₆ = 0.6064623718
- L₇ = 2231
- L₈ = 36.57874
- L₉ = 3.81301
- L₁₀ = 3.47771
- L₁₁ = 0.00

Coordinates of Sites Stored and Displayed in the Geotechnical Database

To facilitate data entry into the geotechnical database, data pertaining to any selected coordinate system may be entered. Those systems include SPCS 27, SPCS 83, degree-minute-second Latitude/Longitude, or decimal Latitude/Longitude. Once data is entered into a selected coordinate system, algorithms, described previously, in the geotechnical database automatically convert the entered data into the coordinates of the other coordinate systems and automatically display on the screen all coordinates for all coordinate systems. For example, other coordinate systems will automatically convert to other system’s coordinates by corresponding formulas, as described in the previous sections, only decimal Latitude/Longitude data will be saved to the database. When the existing decimal Latitude/Longitude data are retrieved, the coordinates of the other three systems are calculated and displayed on the screen, as shown in Figure 14.

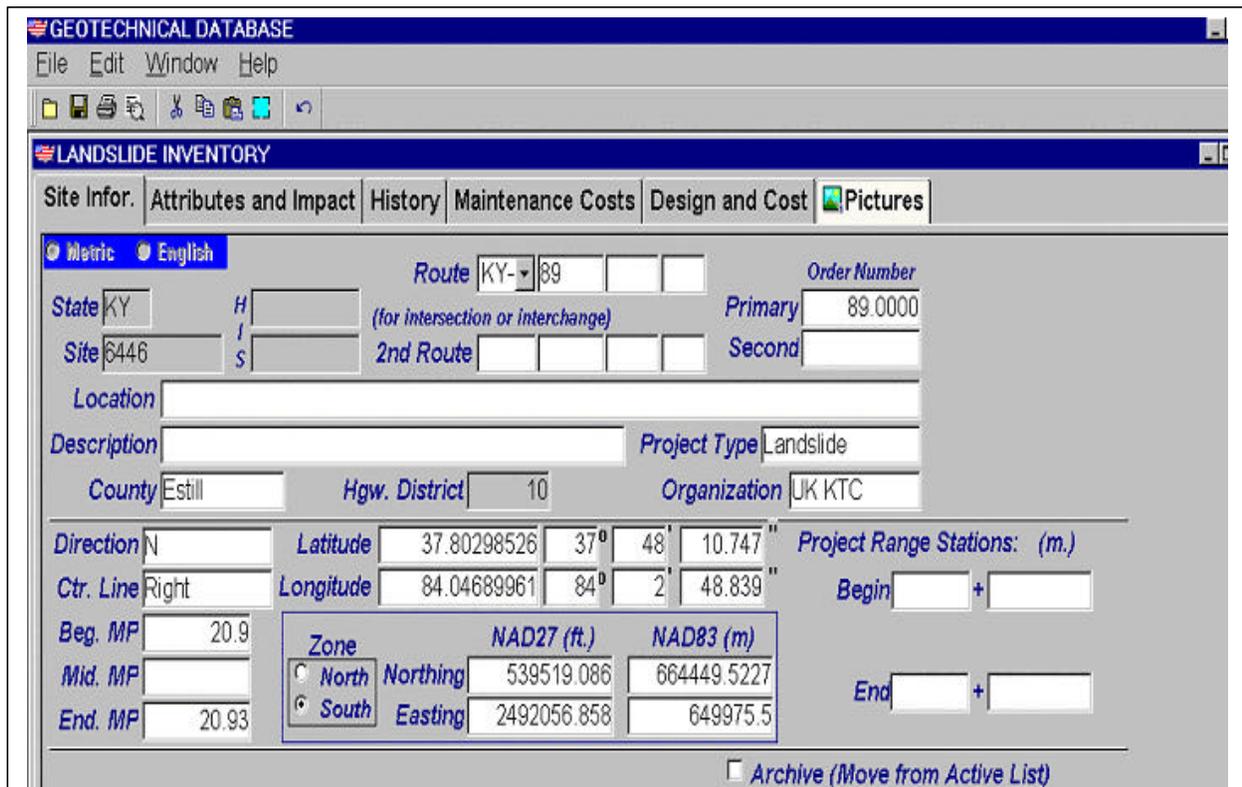
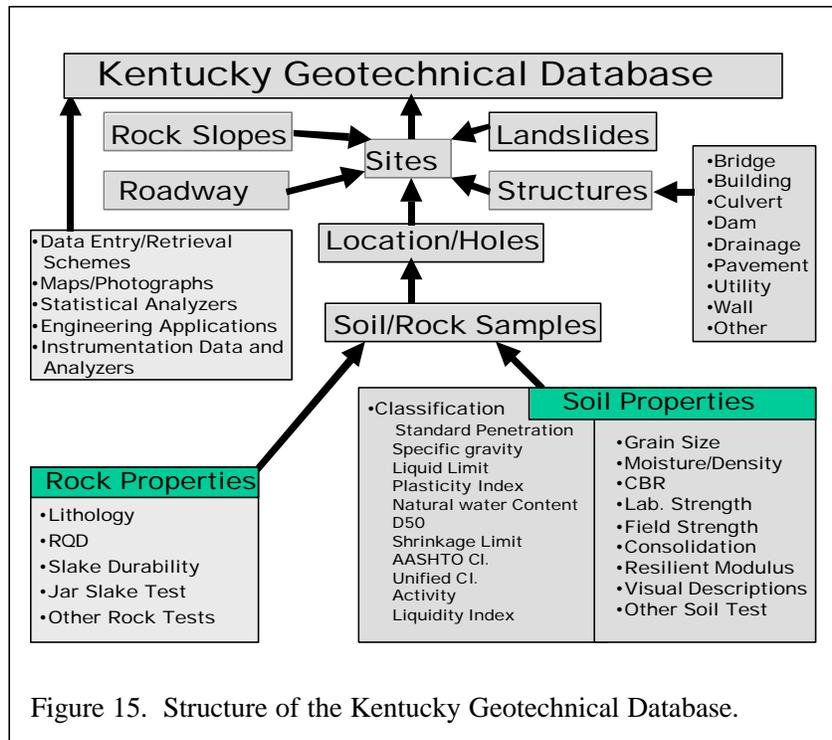


Figure 14. Display of coordinates in different coordinate systems.

GENERAL DATABASE STRUCTURE

The main objective of a database application is to devise a system for entering, retrieving, and analyzing data, effectively and efficiently. To achieve these aims, many different datum categories were created within the geotechnical database. To use them effectively, the different datum categories not only have to be isolated individually, but they also have to be linked together in the database. For this purpose, and to create a hierarchy that is logical, flexible, and easy to understand, the database was divided into several different levels to accomplish a “tree-like” design and linked using primary and foreign keys (Aronoff et al). A primary key is a column or a set of columns that uniquely identifies each row in a table. A foreign key is a column or a set of columns that contains primary key values from another table. Each item in the column or columns must correspond to an item in the column of the other table. There are natural and relational connections among those geotechnical data by location. Based on location, the data are divided into different levels. The location/site is the highest-level datum. Any geotechnical datum has that information. Below that level are different project categories, more detail and



lower level data such as holes, sample, and properties. Under this relational structure, storage requirements of the database are minimized.

The “tree-like” structure and datum relationships of the different components of the Kentucky Geotechnical Database are illustrated in Figure 15. The data are partitioned into five major categories:

1. Rock Slope Database
2. Landslide Database
3. Roadway Database
4. Structures Database
5. Soil and Rock Engineering Database

Structures include bridges, buildings, culverts, dam, drainage, pavement, utility, wall, and other types of structures identified in the future. Test properties of soils include classification, grain size, moisture-density relations, CBR, field and laboratory strengths, consolidation, resilient modulus, and visual description. Test results entered in the classification category include

specific gravity, liquid limit, plasticity index, natural water content, D_{50} , shrinkage limit, AASHTO soil classification, unified soil classification, soil activity, and soil liquidity index. Test properties of rocks include lithology, rock quality designation (RQD), slake-durability, jar slake test, visual descriptions, and unconfined compressive strength. Other components of the database include data entry and retrieval schemes, analytical and design applications, statistical analyzers, and electronic photographs and maps.

DETAILED DESCRIPTION OF ROCK SLOPE MANAGEMENT PROGRAM

A general overview and brief descriptions of the major components of the geotechnical database are given below. A detailed discussion of the rock slope database and management system is presented after this section. Detailed descriptions of the landslide database management system are presented in a companion report.

Main Menu

The main menu of the geotechnical database is shown in Figure 16. When the “Add a New Project” is clicked, the graphical user interface illustrated in Figure 17 appears. The user may add a rock fall or landslide site, or any other type of site. Other types of highway sites include roadway, bridge, building, culvert, dam, drainage, pavement, wall, and “other.” The GUI screen shown in Figure 18 appears when “Site” on the menu is clicked. The site screen contains an array of data entry slots for any array of site data. This includes such information as route number, hole, or boring, information, station numbers, intersecting routes, verbal description, mileposts, values of latitude and longitude, or NAD 27, or NAD 83, coordinates and other information as shown in the figure.

As shown in Figure 17, the site menu also contains special data entry GUI screens for rock fall and landslide sites. Screens for these types of sites, as well as full discussions on the inventories of rock slope and landslide sites in Kentucky are described in more detailed in the following sections.

Rock Slope Data and Management System

Effective management of rock slope problems requires a system that will help identify potentially hazardous sites where rock fall may occur. Also, the system should be simple and clearly identify the important parameters that largely controls the rock fall potential of a cut slope. A rock fall hazard rating system (RHRS), developed by the Oregon Department of Transportation for the Federal Highway Administration, met the conditions cited above. Details are given elsewhere (Pierson and Vickle 1993; Pierson 1993). The rating system provides a rather simple and uniform means of identifying potentially dangerous rock fall slopes and a method for developing a priority list of sites where protective measures, or repairs, may be needed.

When using the RHRS approach, rock slopes are initially classified, visually, for the potential of falling rocks entering the roadway. Rock slopes assigned to the classification, “A,” have high potential for falling rocks entering the roadway, as illustrated by the slope in Figure 19. A “B” classification indicates a moderate chance for rocks entering the roadway. Figure 20 is a view of

a typical “B” slope. Slopes with a low chance of falling rocks entering the roadway are classified as “C”, as illustrated in Figure 21. A large number of slopes on a selected route can be surveyed quickly by merely driving the route and assigning each slope to one of the three categories. Historical information can be used in the preliminary classification. RHRS is a proactive way to address problematic rock slopes and is a very useful tool to assist in allocation of funds to repair hazardous rock cuts (Pierson and Vicle).

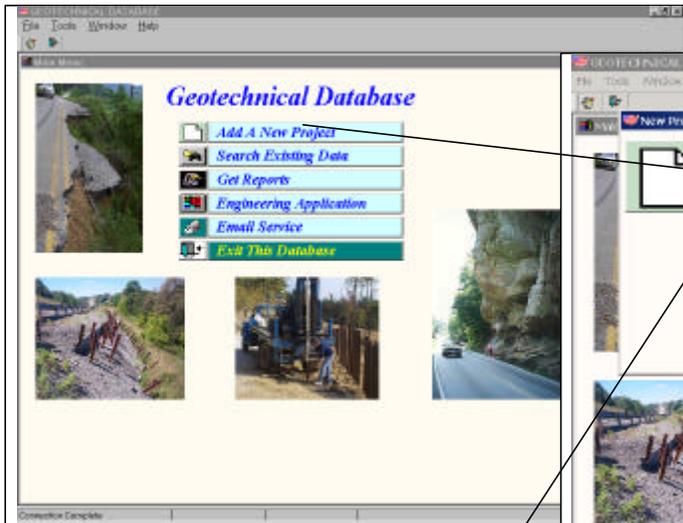


Figure 16. Main menu of geotechnical database.

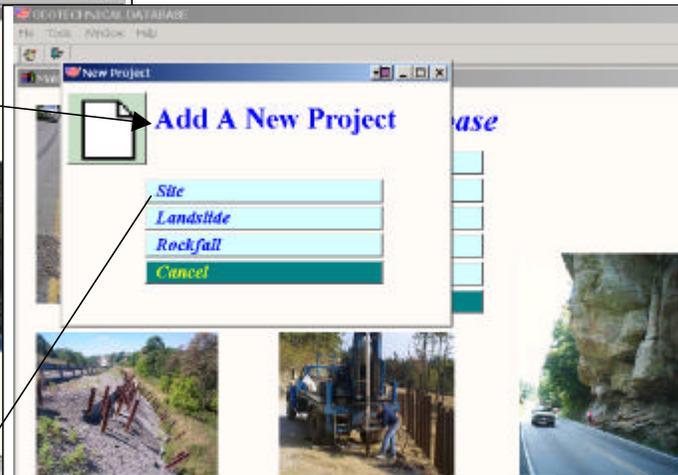


Figure 17. Menu for adding site information.

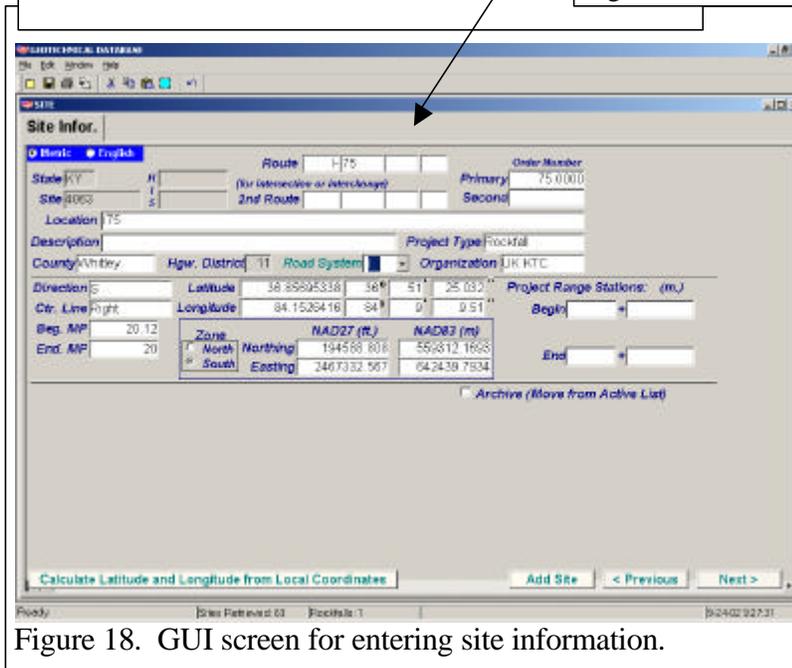


Figure 18. GUI screen for entering site information.

After obtaining preliminary ratings, slopes that were assigned (subjectively) to A and B categories are rated numerically using the RHRS approach. Detailed numerical ratings of rock slopes are based on 12 categories, or attributes. These include slope height, ditch effectiveness, average vehicle risk, percent of decision sight distance, roadway width, geologic character (Case 1--rock jointing and friction between joints) or geologic character (case 2--differential erosion features and differential erosion rates), block size or volume, climate, and rock fall history. The

system provides a good means of assessing the risk associated with a site. Scoring graphs, based on an exponential scoring system, have been established for each category.

All components of the RHRS approach have been programmed into the Kentucky Geotechnical Database using Graphical User Interface (GUI) screens. In cases involving scores between set points, the program provides the range of scores that can be entered and controls

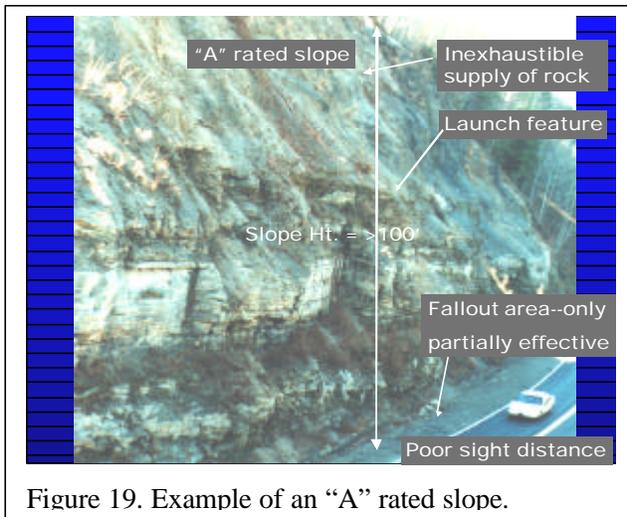


Figure 19. Example of an “A” rated slope.



Figure 20. Example of a “B” rated slope.



Figure 21. Example of a “C” rated slope (After Pierson and Vickle 1993).

allowable values the user can enter. Total score is automatically tabulated after the user has entered all data for all parameters. Spaces are available to enter comments relative to each category or the rock fall site. Any comments entered are displayed on printed reports. Preliminary surveys of about 10,000 rock slopes on interstates, parkways, primary routes, and some secondary routes in Kentucky were surveyed. Approximately 2,086 rock slopes assigned to categories, “A” or “B,” were rated numerically (9). Latitude and longitude of each site were obtained using GPS equipment. Also, photographs of each site were obtained. All data, including electronic photographs have been stored in the database.

A rock slope is considered a site in the database. Site information includes county, route, mile point and station if known. Space is also available to enter location and description comments. Rock slope data for slopes is entered to the database by use of graphical user interface screens. A site screen is shown in Figure 18. This example shows a slope is on Interstate 75 in Whitley County, from MP 20.0 to 20.12. Global Positioning System (GPS) coordinates can be entered as decimal degrees, degrees- minutes- seconds, or in State Plane coordinates formats. When coordinates are entered in one format, the others are automatically calculated. GPS coordinates are used to display the sites on electronic maps embedded in the program.

Detailed Explanation of Graphical User Interfaces for entering rock slope data

Site GUI Screen

The **Site Screen**, as illustrated in Figure 22, contains information about the physical location of a particular rock slope site. **State** is automatically entered. The same screen, Figure 22, is used in the landslide inventory,

roadway, structure, and soil/rock modules of the Kentucky Geotechnical Database.

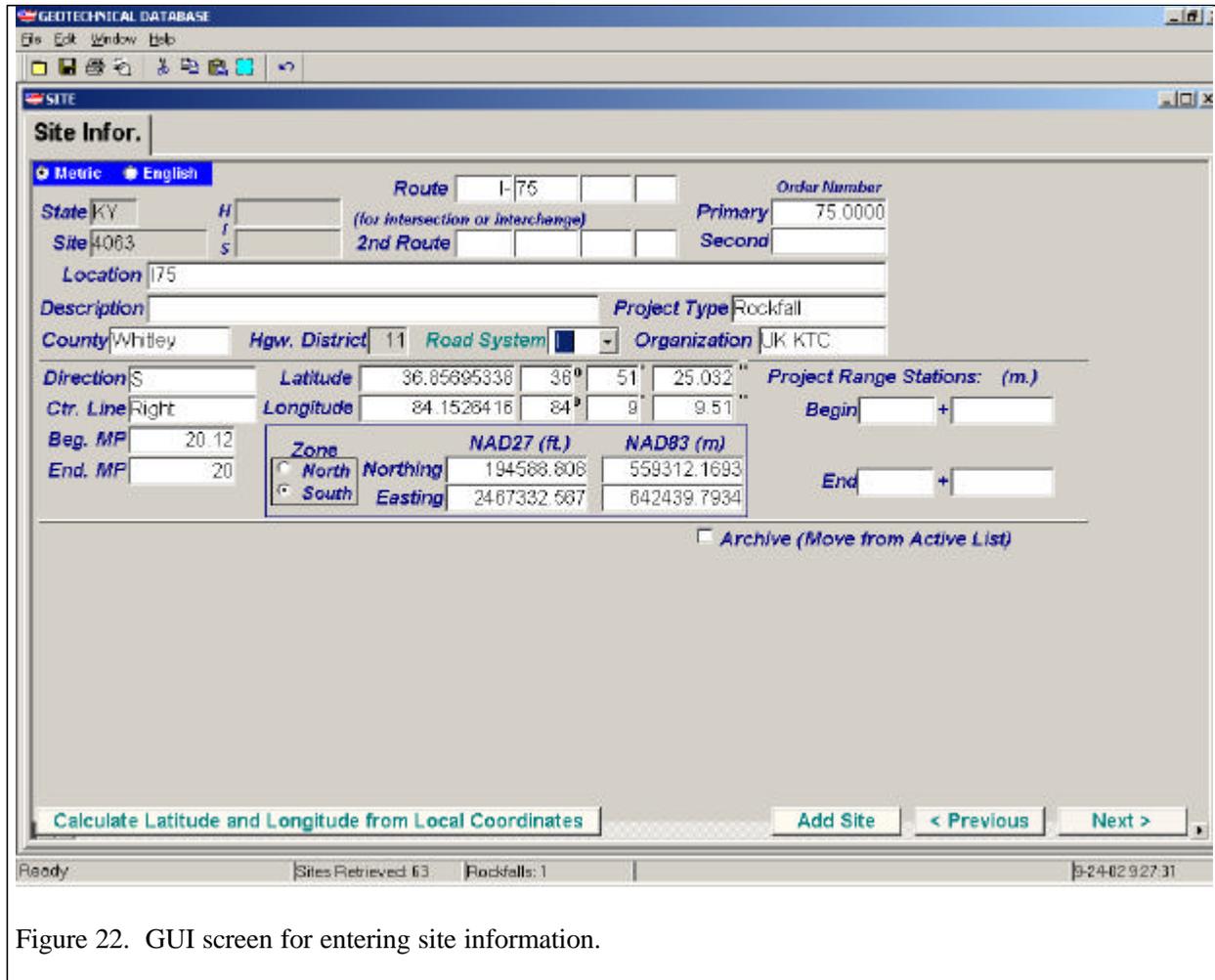


Figure 22. GUI screen for entering site information.

Route: **Route** can be selected by entering the **Route** number in the center box after **Route** (that is, 75). A prefix can be selected from a drop down list in the first box (for example, I for Interstate, Figure 23). Clicking the mouse in the blank box and using the down arrow button to make a selection activates the drop down list. The first letter of the selection can also be typed and the appropriate selection appears. For example, typing **K** in the box will enter **KY** for route prefix and **U** would enter **US**. Selecting the prefix from the drop down list and entering the Route Number in the next box enters route. A suffix can also be entered when applicable. A Route suffix can be added by clicking the mouse in the blank box and using the button to make a selection or the first letter of the selection can also be typed and the appropriate selection appears. For example, typing **W** in the box will enter **W** for Route Suffix.

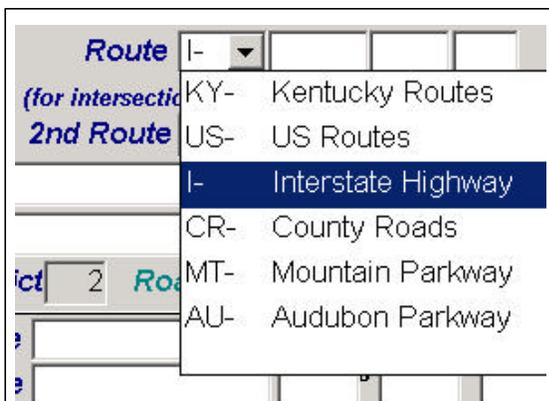


Figure 23. Dropdown list for entering route prefix.

Site is a unique number that is automatically assigned by algorithms stored in the database program. The term, **2nd Route**, is reserved for



Figure 24. Dropdown list for entering the type of project.

intersections of roadways. It is not used in the *Rock fall* module of the database.

Order Number, Primary, and **Secondary** apply to roadways within the county and are automatically assigned by a Database Administrator (DBA).

Location is for entering additional information concerning the location of the rock slope. **Description** is for entering additional information.

Project Type is selected by using the drop down list, Figure 24, or the first letter of the **Project Type** can be typed in the adjacent box or be selected from a drop down list box. It is always **Rock fall** when using the *Rock fall* module of the database.

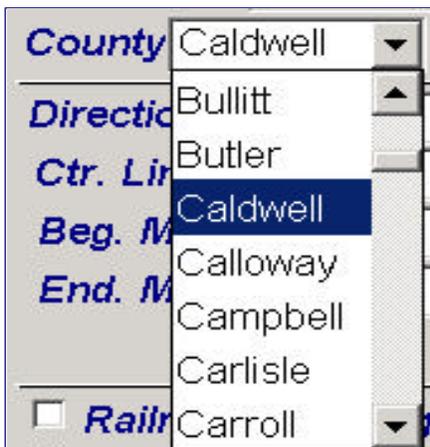


Figure 25. Dropdown list for entering the county name.

Clicking the mouse in the blank box and using the drop down list, Figure 25, a **County** selection may be made, or the first letter of the **County** can be entered. The first **County**, in alphabetically order, will appear. The user may scroll down to the desired County. Typing **C** in the box will go to Caldwell County. If Carroll County is needed, then the user scrolls down to find Carroll or the user types C and scrolls down from Caldwell. The **Hgw. District** automatically assigns the appropriate Highway District number when the County is entered. The type of **Road System** is selected from a drop down list, Figure 26. For example, **SS** means the “state secondary” system.

Organization is selected by using the drop down list, Figure 27, to make a selection, or the first letter of the **Organization** entering the information can be typed in the adjacent box. For example, typing **U** would return UKTC, which means the University of Kentucky Transportation Center entered this rock fall site. Selecting **K** means the Kentucky Transportation Cabinet entered the site information. In

structuring the database, allowance has been made for consulting organizations to enter data in the future.

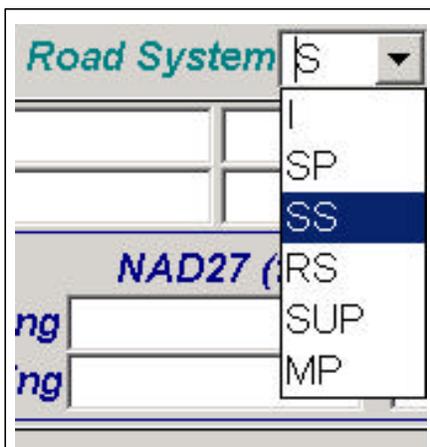


Figure 26. Dropdown list for entering the type of road system

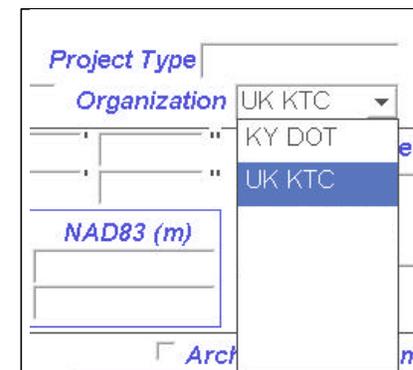


Figure 27. Dropdown list for entering the type of organization.

allowance has been made for consulting organizations to enter data in the future.

Dir. refers to lane direction the slope is adjacent to. The direction can be typed or selected from a drop down list box, Figure 28,. **Ctr. Line** is the offset direction (**Right or Left**) from the centerline of the roadway. The offset direction can be



Figure 28. Dropdown list for entering the route direction adjacent to the rock slope.

typed or selected from a drop down list box by using drop down list to make a selection.

Beg. MP, **Mid MP**, or **End MP** refers to the beginning, middle, and ending mile point of the slope being rated, respectively. Only the **Beg. MP** and **End MP** are used in the *Rock fall* module of the database.

Latitude and **Longitude** are entered as decimal degrees or **Degrees (?) Minutes (') and Seconds (")**. If **Latitude** and **Longitude** are entered in decimal degrees (up to 8 decimal places) they are automatically converted to **Degrees, Minutes and Seconds**, and vice versa. The decimal place must be typed in when **Longitude** is entered in Decimal Degrees (i.e. 84.50000000). The decimal is automatically entered for **Latitude** (i.e. 34.50000).

State Plane Coordinates are automatically calculated when **Latitude** and **Longitude** are entered. They are displayed in two North American Datum (NAD) methods: **Northing** and **Easting, NAD 27 (Ft)**, feet and **NAD 83, (m)** meters. **North** and **South Zone** are also selected. **State Plane Coordinates** can also be entered and **Latitude** and **Longitude** will be calculated as decimal, degrees and degree, minutes, and seconds.

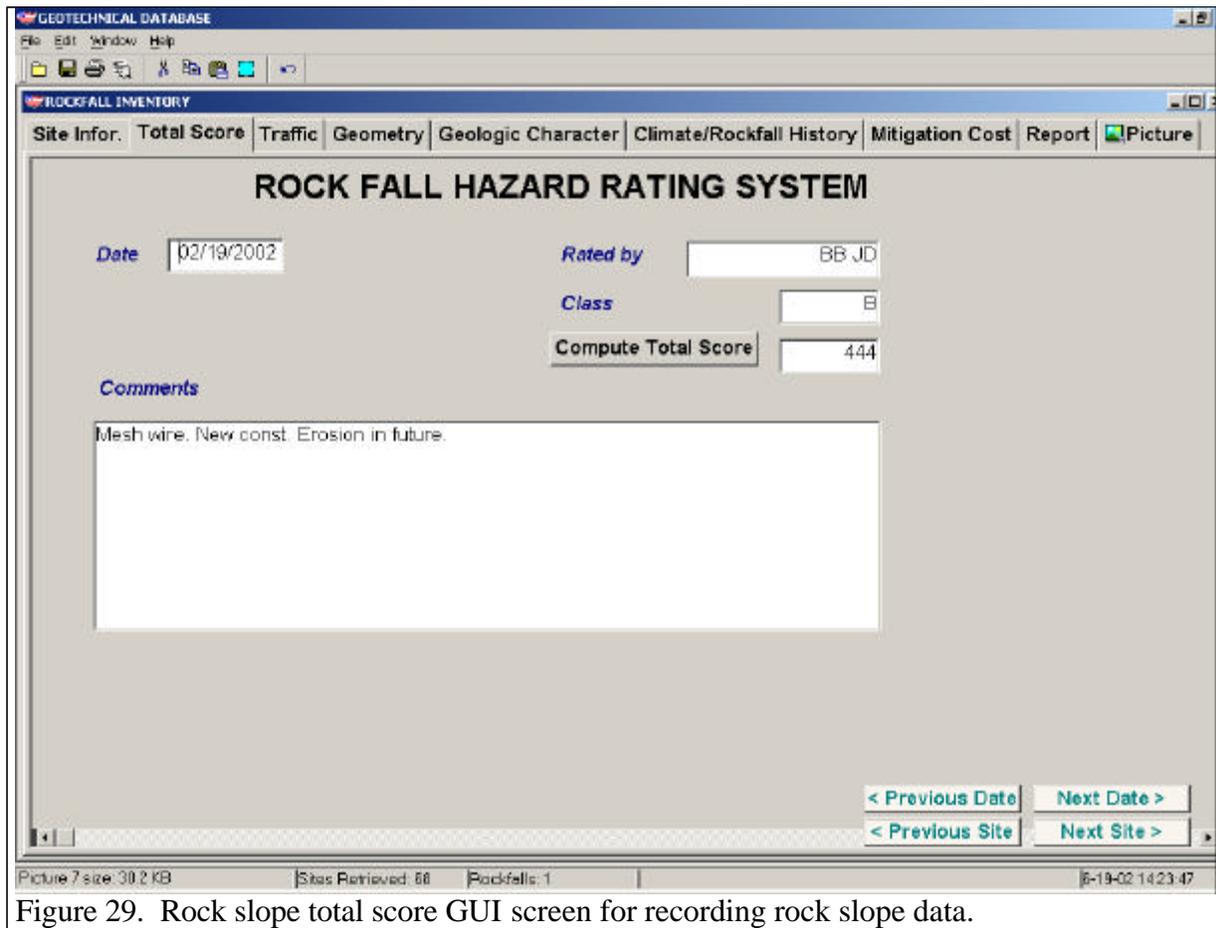


Figure 29. Rock slope total score GUI screen for recording rock slope data.

Project Range Stations can be entered as **Begin** (Beginning) and **End** (Ending) stations if known. Stations can be entered in English or Metric formats. Stations can be entered to the hundredth of a foot or meter.

Rock Slope Total Score Screen

The **Total Score** screen, Figure 29, is used to record the Date, Class of Slope, typically A or B if it is rated, person or persons who performed the rating, and any comments. The numerical RHRS score is calculated by clicking the **Compute Total Score** tab after the rock fall parameters have been entered. Rock slope parameters and other data are arranged near the top of the total score GUI screen in the forms of tabs. These tabs have been labeled **Site Infor., Total Score, Traffic, Geometry, Geologic Character, Climate/rock fall History, Mitigation Cost, Report, and picture.** Clicking any one of these labeled tabs causes a GUI screen to appear for entering data pertaining to that tab.

Date: The rating date is entered in this field, as shown in Figure 29. **Rated by:** Enter the name or initials or the person(s) rating the slope.

Class: Enter the preliminary classification of the slope **A, B, or C** by typing or using the drop down list, Figure 30, to make a selection. **Comments:** Any comments can be entered here. This example is recording the roll number and picture numbers from developed prints from the site. Any comment entered appears on the report screen. **Compute Total Score:** After entering all information and scores, return to this page and click “**Compute Total Score.**” The **Total Score** of the numerically rated rock slope assigned to the site will be computed.

When the tab labeled “**Traffic**” (Figure 29) is clicked using the mouse, the **Traffic Information** screen (Figure 31) appears. This screen is used to calculate the Average Vehicle Risk and the Percent of Decision Sight Distance scores. The Average Vehicle Risk score determines “the risk associated with the percentage of time a vehicle is in the rock fall section” (Pierson and Vickle, 1993). It is automatically calculated when the speed limit, which can be typed or selected from a drop down list, slope length, and Average Annual Daily Traffic (AADT) obtained from the Kentucky Transportation Cabinet (KYTC) are entered. The algorithm for calculating the average vehicle risk is, as follows:

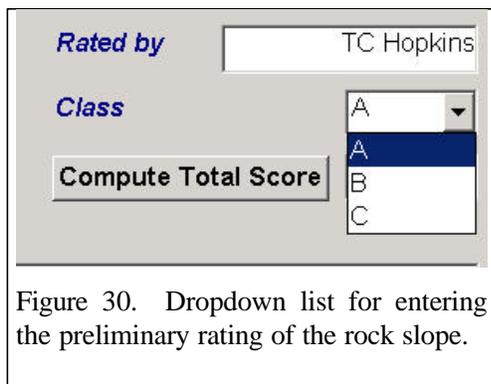


Figure 30. Dropdown list for entering the preliminary rating of the rock slope.

$$AVR = \frac{ADT(cars/day)}{24hours/day} \times \frac{Slope\ Length\ (miles)}{Posted\ Speed\ Limit\ (miles\ per\ hour)} \times 100\% \tag{5}$$

where

ADT = Average daily traffic.

The **Posted Speed Limit** is normally obtained from the posted speed limit on roadway signs, Figure 32, near the site. The relationship between the AVR category score and percent of time a vehicle is in the rock slope section is shown in Figure 33. When the rating is 100 percent, a

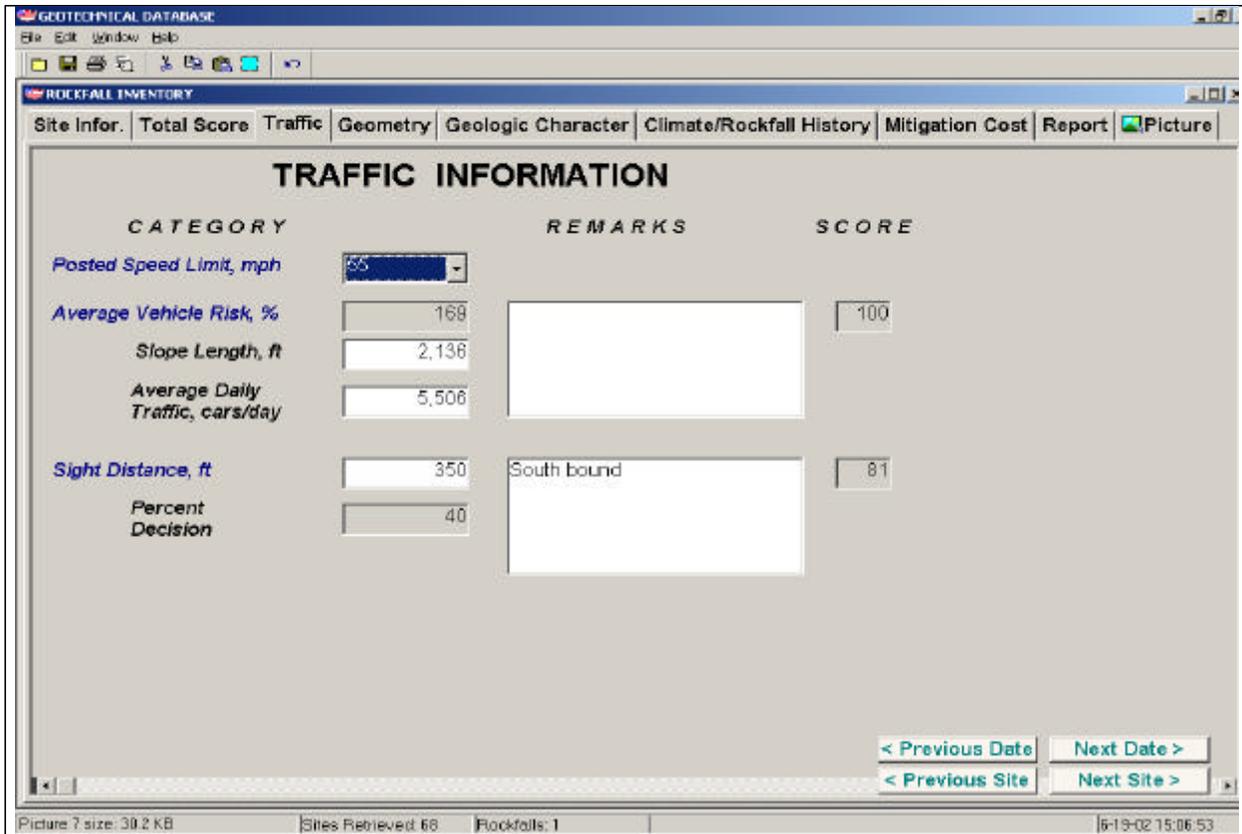


Figure 31. GUI traffic information screen for scoring the average vehicle risk and sight distance.

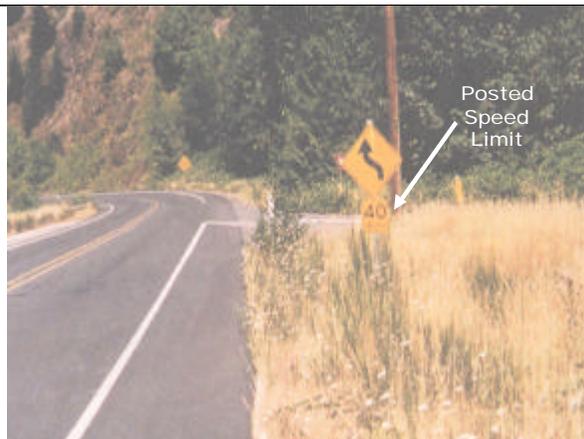


Figure 32. Posted speed limit sign (after Pierson and Van Vickle, 1993)

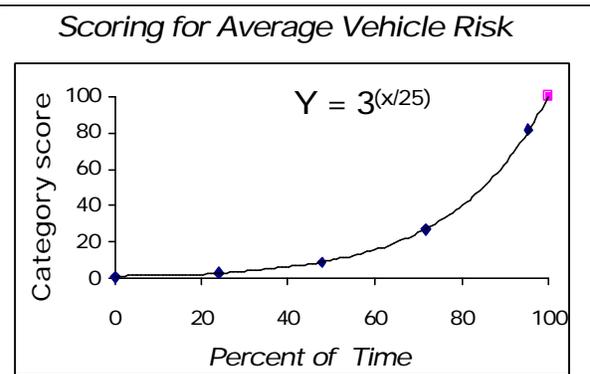


Figure 33. Category score as a function of the percent of time a vehicle is in the measured rock slope section.

vehicle can be expected to be present in the slope section 100 percent of the time. If the calculated percent is greater than 100 percent, then more than one vehicle is present in the section at any given time.

“The Percent of Decision Sight Distance,” PDSD, compares the amount of sight distance available through a rock slope section to the low amount (Figure 34) prescribed by AASHTO (Pierson and Vickle 1993), or

$$PDSD = \frac{AST}{DSD} \times 100\% \tag{6}$$

where

AST = Actual sight distance and
 DSD = Decision sight distance.

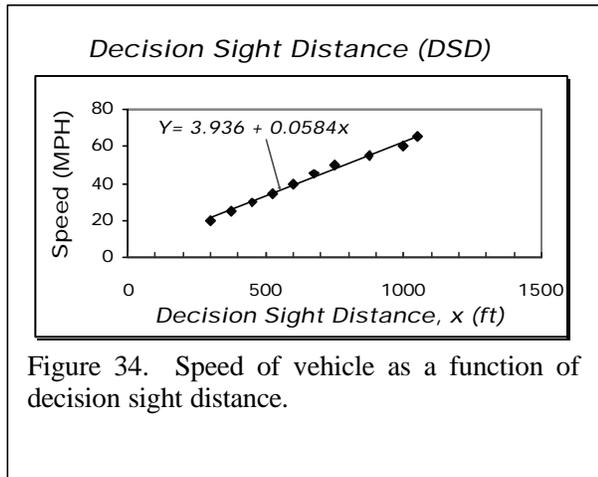


Figure 34. Speed of vehicle as a function of decision sight distance.

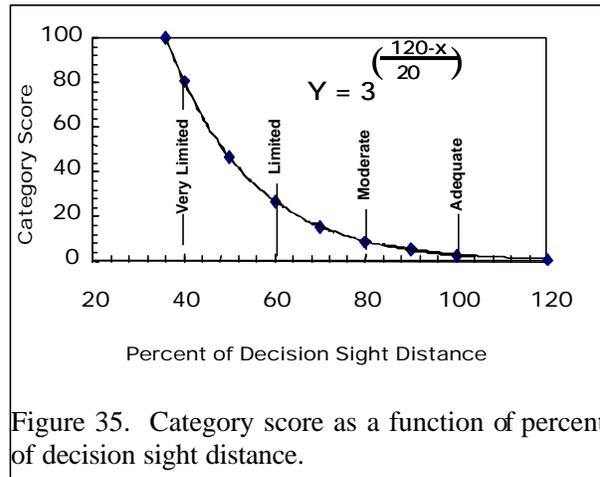


Figure 35. Category score as a function of percent of decision sight distance.

The category score is shown in Figure 35 as a function of the percent decision sight distance.

After entering values for the posted speed limit, horizontal slope length, ADT, and sight distance, the program automatically computes the average vehicle risk and percent decision sight distance. Based on the computed values of average vehicle risk and percent decision sight distance, category scores are computed for these two parameters.

Clicking the tab in Figure 29, identified as **“Geometry,”** causes the geometry GUI screen to appear, as shown in Figure 36. This screen is used to **enter data pertaining to the Slope Height, Ditch Effectiveness, and Roadway Width.**

The Slope Height score is based on the principal that the taller a slope is the greater the likelihood for falling rocks to enter the roadway. The relationship of the category score and slope height is shown in Figure 37. Two situations oftentimes encountered are depicted in Figures 38 and 39. In the first case, the height of slope involves only the height of the cut slope. In the second situation, Figure 39, the height of slope includes the height of the cut slope and the height of the natural slope situated above the cut slope.

Slope height may be entered directly (Figure 36), or an approximate value may be determined by measuring two angles, θ_1 and θ_2 , using a hand held instrument (inclinometer), as illustrated in Figures 40, 41, and 42. Using an inclinometer, the angles, θ_1 (Figure 41), and θ_2 (Figure 42) may be measured from the horizontal to the same point at the top of the slope. A distance, X, between the points where the two angles were obtained is determined, and a height of instrument (HI) is measured. **Slope Height, SH**, is determined by:

$$SH = (\sin \theta_1 - \sin \theta_2) X / \sin(\theta_1 - \theta_2) + HI. \tag{7}$$

In the computer program, when the parameters, θ_1 , θ_2 , X, and HI are entered into the GUI screen shown in Figure 36, the slope height and the slope height category score are automatically calculated.

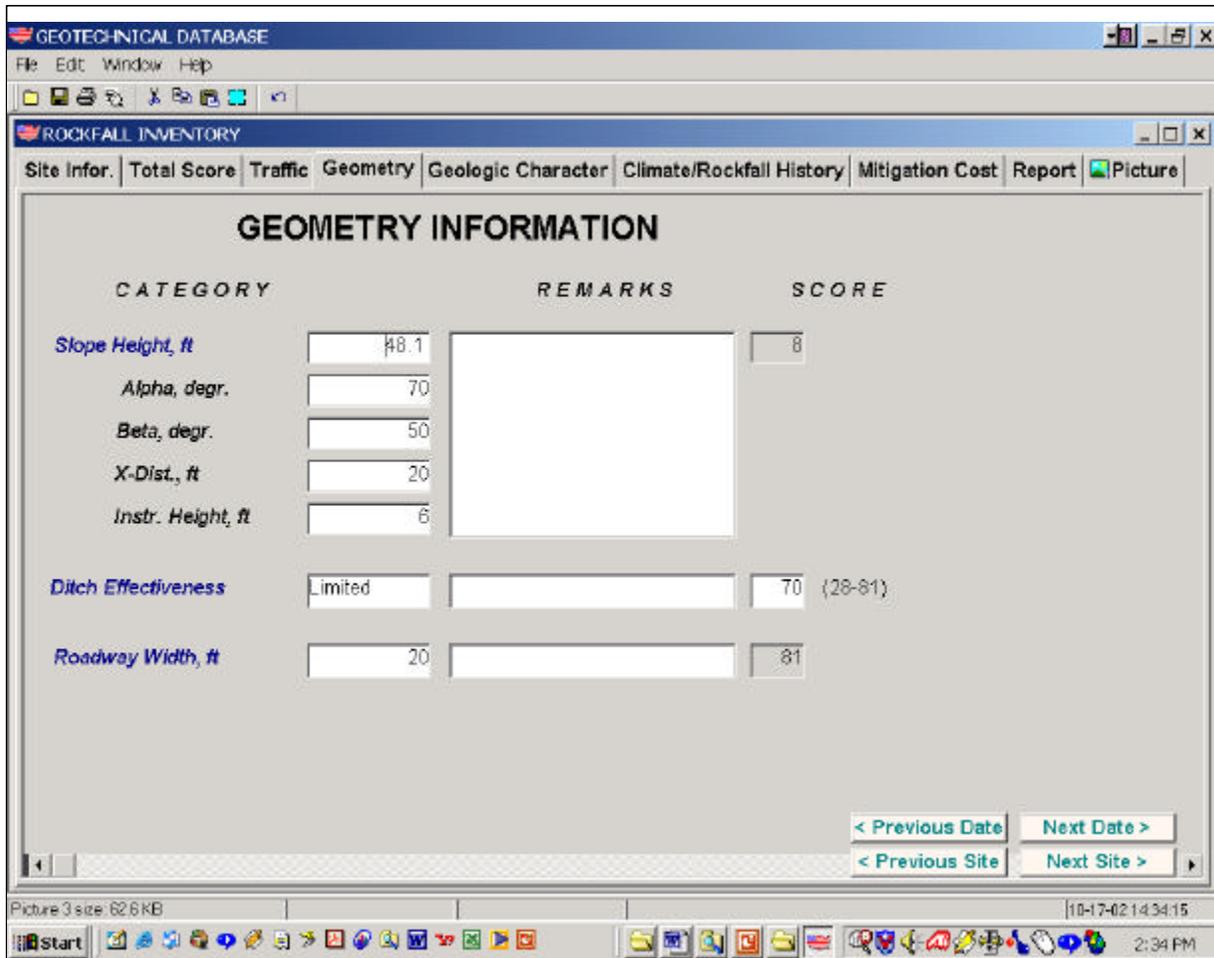


Figure 36. GUI screen for entering the geometry of a rock slope.

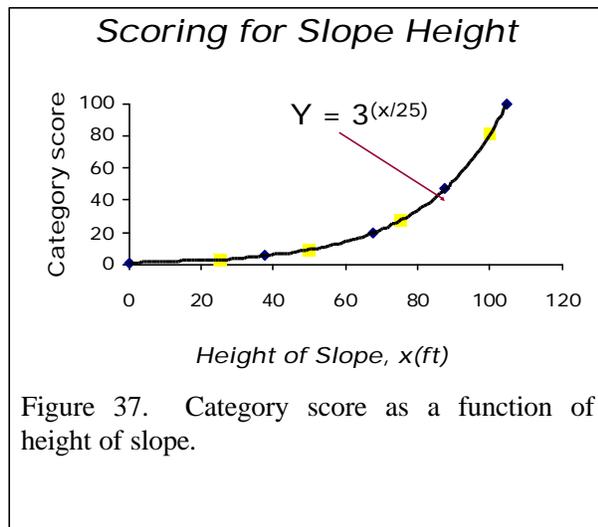


Figure 37. Category score as a function of height of slope.

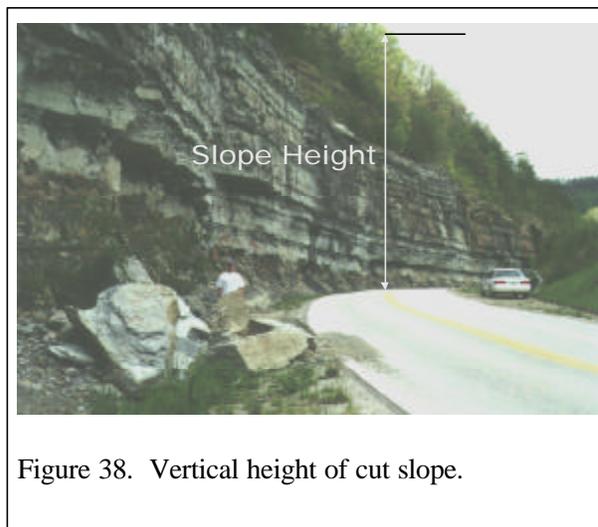


Figure 38. Vertical height of cut slope.

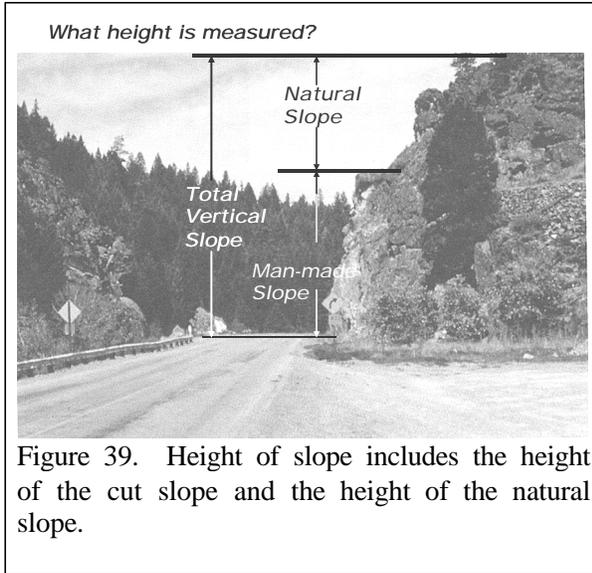


Figure 39. Height of slope includes the height of the cut slope and the height of the natural slope.

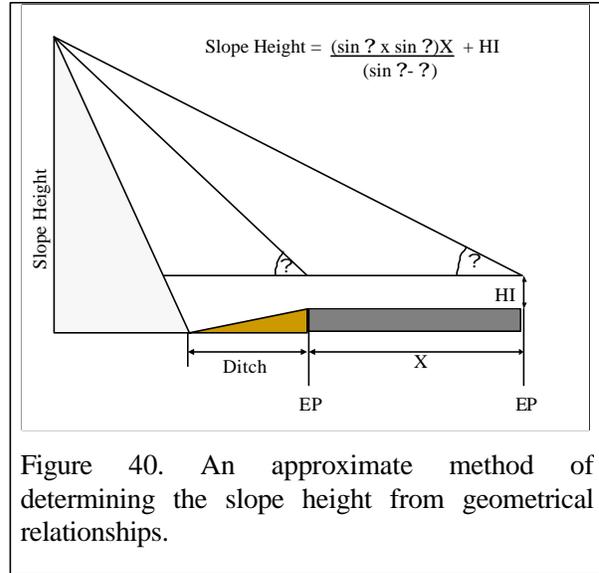


Figure 40. An approximate method of determining the slope height from geometrical relationships.

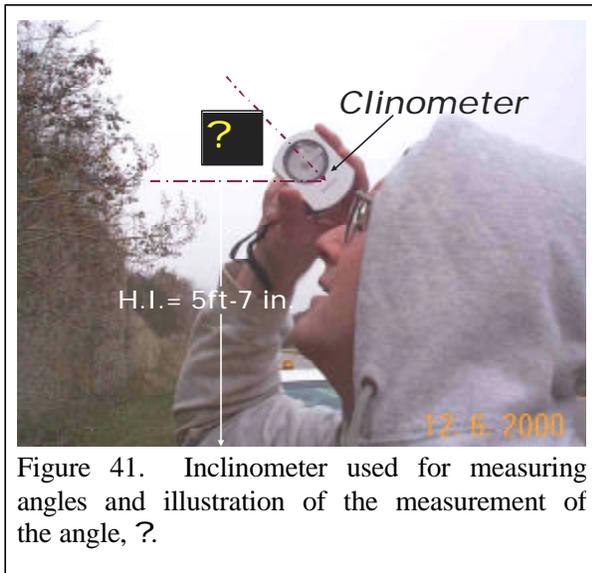


Figure 41. Inclinometer used for measuring angles and illustration of the measurement of the angle, ?.

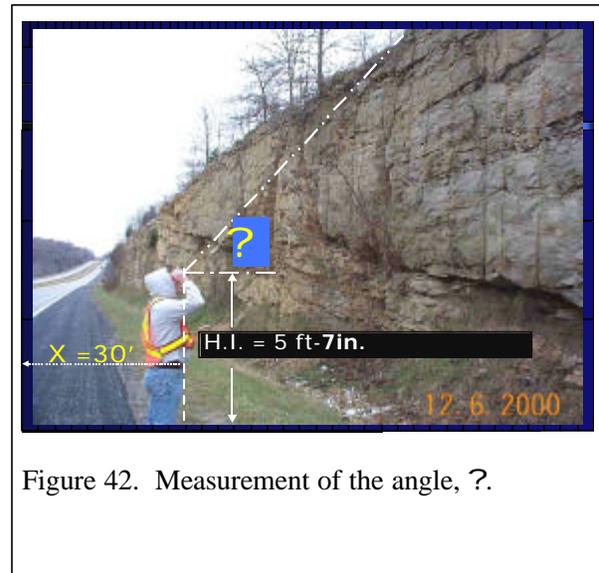


Figure 42. Measurement of the angle, ?.

Ditch Effectiveness is an estimated measure of the ability of the ditch, or the distance between the base of the slope and the edge of pavement, to contain or prevent any falling rock from reaching the paved roadway. Although such parameters as slope height or average vehicle risk are fairly objective in assigning numerical values, the effectiveness of the width of a ditch is subjective. Generally, as the width of the area between the toe of the slope and the edge of pavement increases, the **Ditch Effectiveness** score decreases. Two extreme examples of ditch effectiveness where low and high scores were assigned numerical values of zero and 100 points, respectively, are illustrated in Figures 43 and 44.

In judging the effectiveness of the ditch area to contain rock fall, the user must try to anticipate the quantity of rock fall that may occur and how the quantity of material will “fit” in the ditch, or whether it will spill over into the roadway, or whether it will completely breakdown



Figure 43. The ditch effectiveness of this example was assigned a low score because of the larger space between the toe of the slope and the edge of the pavement.

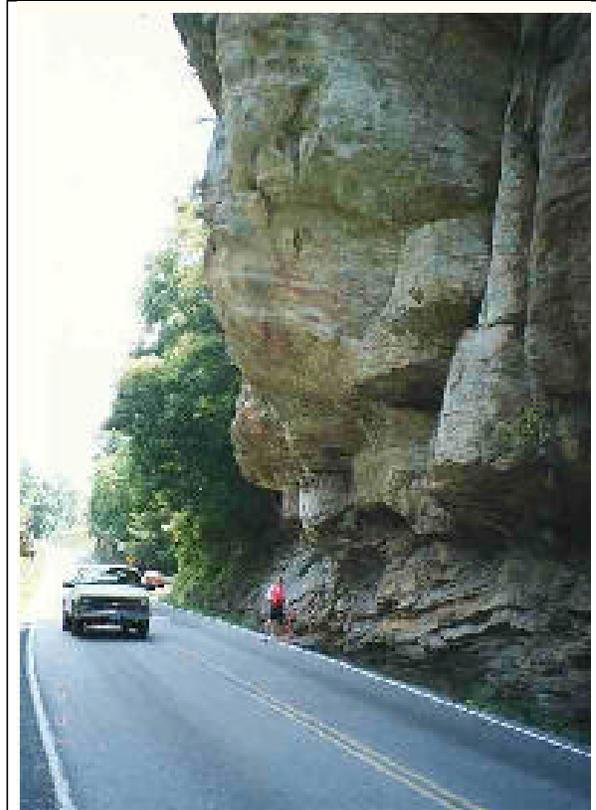


Figure 44. The ditch at this site is ineffective in retaining rock fall and preventing spillage onto the roadway.



Figure 45. Wide fallout area.

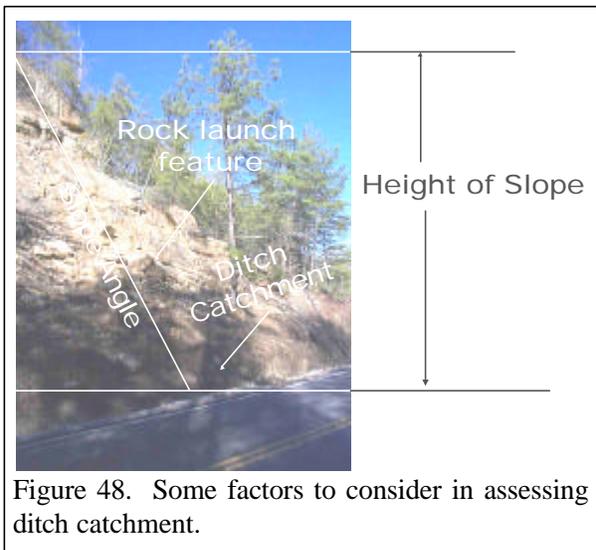
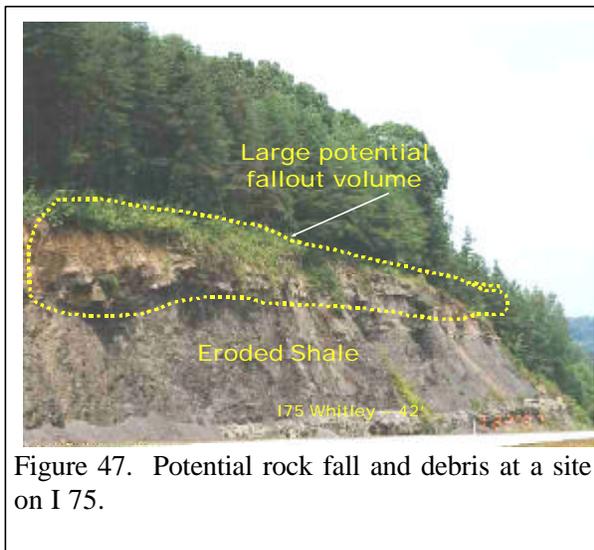


Figure 46. Failure of part of this large volume of material spilled onto the roadway at the I 75 site.

on impact into tiny rock fragments. Although the ditch, or the area between the toe of the slope and the edge of pavement may be quite large, rock fall may in some situations enter the roadway. For example, the site at a location on I-75, Figure 45, appears to have more than adequate room to prevent rock fall spillage onto the interstate. However, as shown in Figure 46, rock fall and debris filled the ditch area (bottom right in photo) and spilled onto the roadway (the photo was obtained after the rock fall and debris had been removed from the roadway). Another view of the slope in Figure 47 reveals that a large volume of hard material was situated above an eroded shale unit.

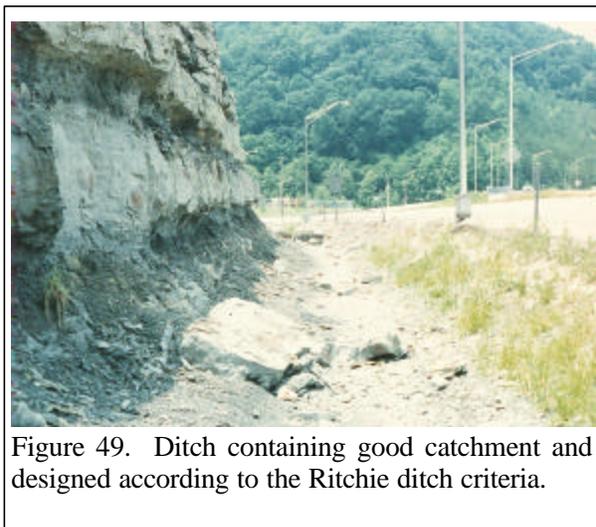
In assigning numerical values to this category, benchmark points (arbitrarily selected as 3, 9, 27, and 81) are associated with descriptions. Scoring this category requires a judgement of the rater. According to Pierson and Vickle (1993), this association is as follows:

- ?? 3 points—Good catchment: all, or nearly all falling rocks, are retained in the catch ditch (see example in Figure 43).
- ?? 9 points—Moderate catchment: falling rocks occasionally reach the roadway
- ?? 27 points—Limited catchment: falling rocks frequently reach the roadway.
- ?? 81 points—No catchment: no ditch, or the ditch is ineffective, and all, or nearly all, of the falling rocks reach the roadway.

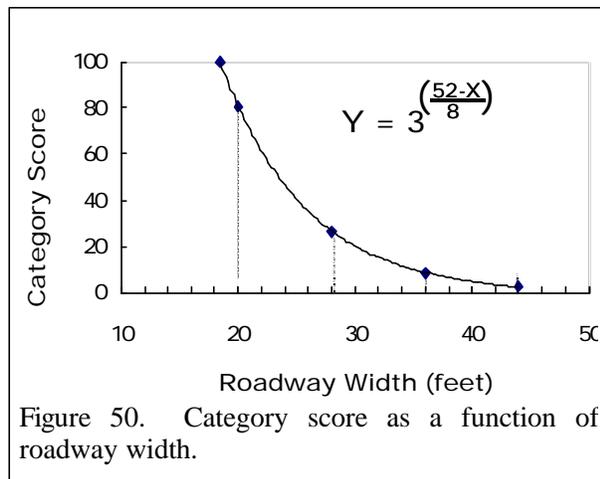


Pierson and Vickle (1993) note that the rater should consider the following factors in evaluating the ditch catchment:

- ?? slope height and angle (See Figure 48)
- ?? ditch width, depth, and shape (see Figure 49)
- ?? anticipated block size and quantity of rock fall (see Figures 47 and 48)
- ?? slope irregularities that could serve to create a rock fall launching feature (see Figure 47).



Roadway Width is scored using the assumption that the wider the roadway the more room a driver has to avoid rock debris that has reached the roadway, including paved shoulders. The measured portion of the roadway width includes the paved shoulders. Category score as a function of roadway width is shown in Figure 50. This category is a measurement of the available maneuvering room, or width of roadway, that allows a driver to miss a rock(s) in the roadway.



After clicking the tab, identified as **Geologic Character** in Figure 29, the GUI screen in Figure 51 appears. The **Geologic Character** screen is used to rate the structural conditions, joints, and bedding planes and differential erosional features and rates, visible on the slope. Joints are fissures in the rock mass. Bedding planes are the interface between different rock layers. The structural condition of joints and bedding planes are considered to be discontinuous if they are more than 10 feet in length. Joint orientation score is based on the relationship between the angles of the joints and the highway. The score is higher if the

orientation of the joints or bedding planes would cause falling rocks to be projected toward the road.

Two cases of **Geologic Character** are considered:

- 1) **Joints and their Orientation to the roadway, and,**
- 2) **Differential Erosional Features and Rates**

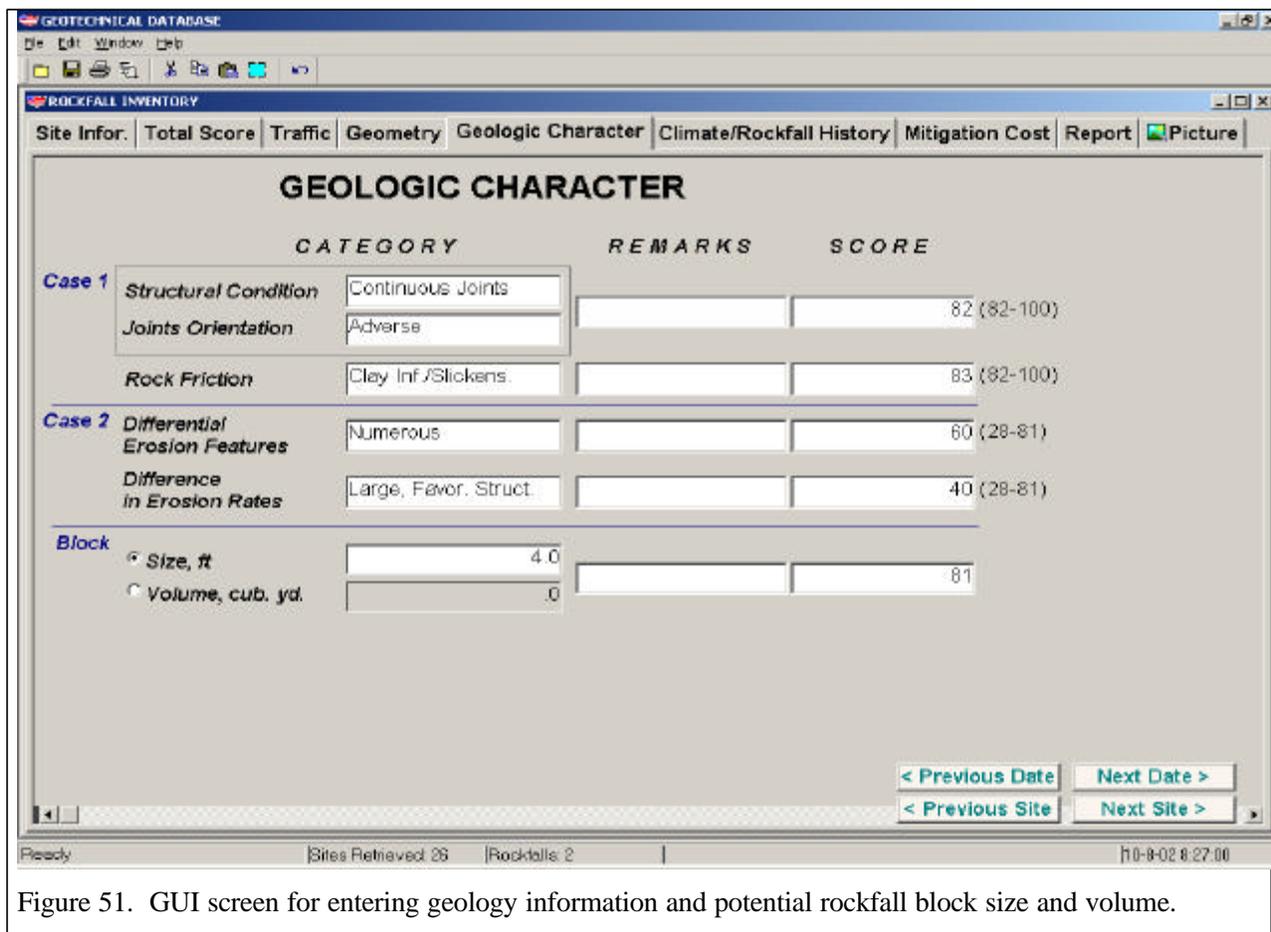


Figure 51. GUI screen for entering geology information and potential rockfall block size and volume.

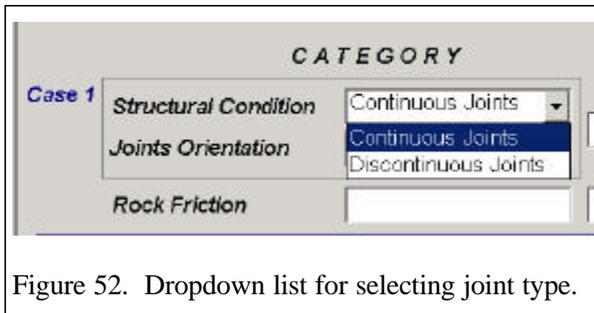


Figure 52. Dropdown list for selecting joint type.

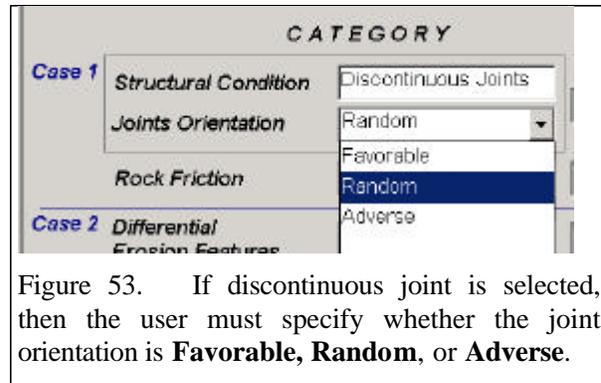


Figure 53. If discontinuous joint is selected, then the user must specify whether the joint orientation is **Favorable**, **Random**, or **Adverse**.

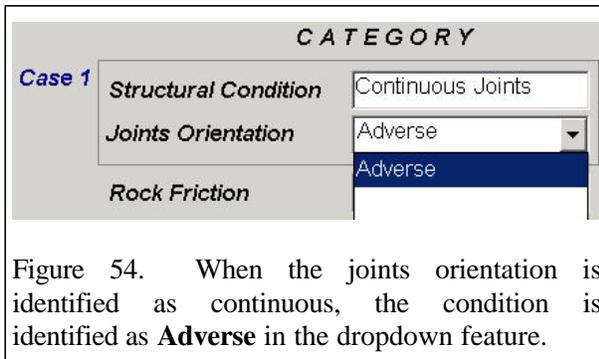


Figure 54. When the joints orientation is identified as continuous, the condition is identified as **Adverse** in the dropdown feature.

Case 1

Structural Condition: Select **Continuous Joints** or **Discontinuous Joints** from the drop down list (Figure 52) or type the first letter of the selection. Joints are **Continuous** if 10 feet or larger in length. **Joint Orientation:** If joint orientation is **Discontinuous**, then the user must select **Favorable**, **Random** or **Adverse** from the drop down list, as shown in Figure 53 (Note: If **Continuous Joints** is selected, **Joint Orientation** must be **Adverse**, as shown in Figure 54 and illustrated in Figures 55 and 56).

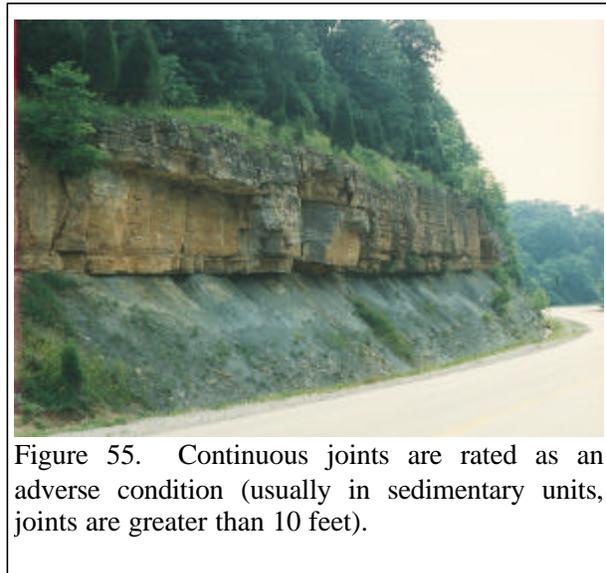


Figure 55. Continuous joints are rated as an adverse condition (usually in sedimentary units, joints are greater than 10 feet).

The **Structural Condition**, case 1, is scored as follows:

If **Discontinuous Joints** and **Favorable Orientation** are selected, then a corresponding **SCORE** ranging from 0 to 9 is entered if **Discontinuous Joints** and **Random Orientation** are selected enter a corresponding **SCORE** from 10 to 27.

If **Discontinuous Joints** and **Adverse Orientation** are selected enter a corresponding **SCORE** from 28 to 81.

If **Continuous Joints** and **Adverse Orientation** are selected enter a corresponding **SCORE** from 82 to 100.

Rock Friction: Select **Rough**, **Planar Undulating** or **Clay infilled Slickensided** from the drop down list, as shown in Figure 57. **Rock Friction** is scored as follows:

If **Rough** is selected, then enter a corresponding **SCORE** ranging from 0 to 9.

If **Undulating** is selected, then enter a corresponding **SCORE** ranging from 10 to 27.

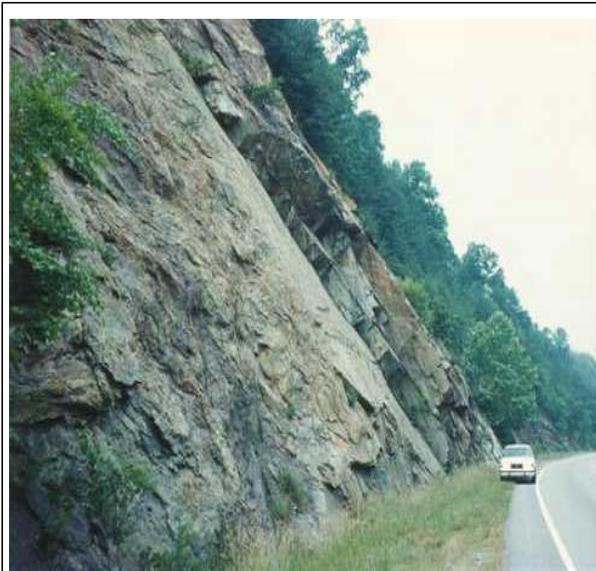


Figure 56. Another example of continuous joints and an adverse condition—tilted layers.

CATEGORY	
Case 1	Structural Condition Discontinuous Joints
	Joints Orientation Random
	Rock Friction Clay Inf./Slickens. ▾
Case 2	Differential Erosion Features Rough, Irregular
	Undulating
	Planar
	Difference in Erosion Rates Clay Inf./Slickens.

Figure 57. Dropdown list for rock friction.

Case 2	Differential Erosion Features Numerous ▾
	Few
	Occasional
	Numerous
	Many
Block	<input type="radio"/> Size ft

Figure 59. Dropdown list for differential erosion features.

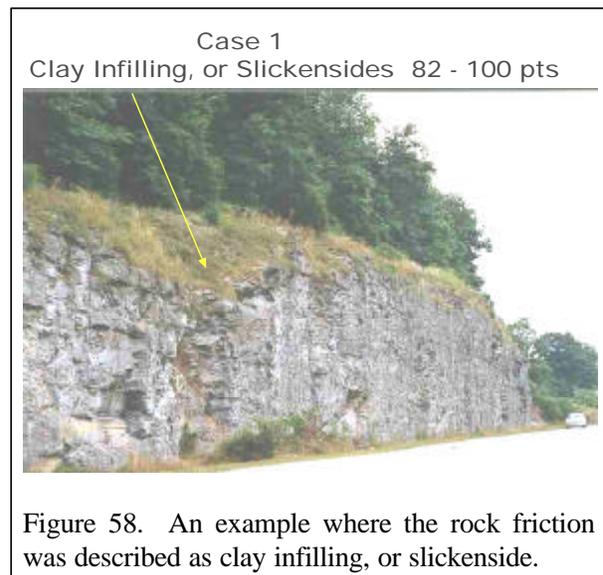


Figure 58. An example where the rock friction was described as clay infilling, or slickenside.

If **Planar** and **Adverse Orientation** is selected, then enter a corresponding **SCORE** ranging from 28 to 81.

If **Clay Infilling/Slickenside** (see Figure 58 for an example) is selected, then enter a corresponding **SCORE** ranging from 82 to 100.

Numerical ratings of the structural condition, Case 2-- **Differential Erosion Features and Rate**—are scored in the GUI screen shown in Figure 51. **Differential Erosion Features** are selected as **Few, Occasional; Many, or major** from the drop down list in Figure 59, or type the first letter of the selection. **SCORE** Differential Erosion Features as follows:

If **Differential Erosion Features Few** is selected, enter a corresponding **SCORE** ranging from 0 to 9.

If **Differential Erosion Features Occasional** is selected, enter a corresponding **SCORE** ranging from 10 to 27.

If **Differential Erosion Features Many** is selected, enter a corresponding **SCORE** from 28 to 81.

If **Differential Erosion Features Major** is selected enter, a corresponding **SCORE** from 82 to 100.

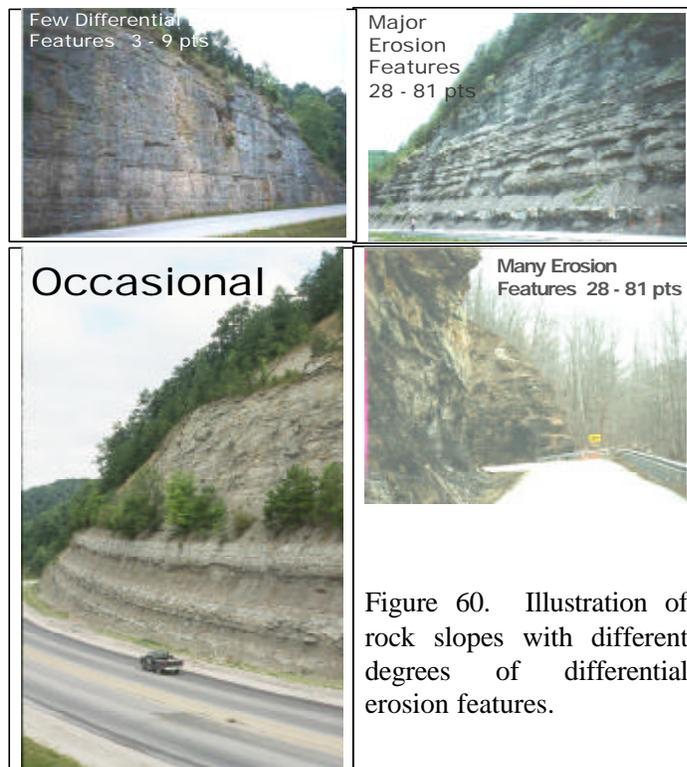


Figure 60. Illustration of rock slopes with different degrees of differential erosion features.

Examples of rock slopes containing different differential erosion features are illustrated in Figure 60.

Differential Erosion Rates are selected as **Select, Small, Moderate, Large, or Extreme** from the drop down list, as shown in Figure 61, and are scored as follows:

If **Differential Erosion Rates Small** is selected, then a corresponding **SCORE** ranging from 0 to 9 is entered

If **Differential Erosion Rates Few** is selected, then a corresponding **SCORE** ranging from 10 to 27 is entered

If **Differential Erosion Rates Large** is selected, then a corresponding **SCORE** ranging from 28 to 81 is entered

If **Differential Erosion Rates Extreme** is selected, then a corresponding **SCORE** ranging from 82 to 100 is entered.

Examples of rock slopes with different erosion rates are illustrated in Figure 62.

Block: This category describes the material falling from the rock slope. If **Size** of the block is the deciding factor in determining the type of material falling, click the **Size** button and enter the

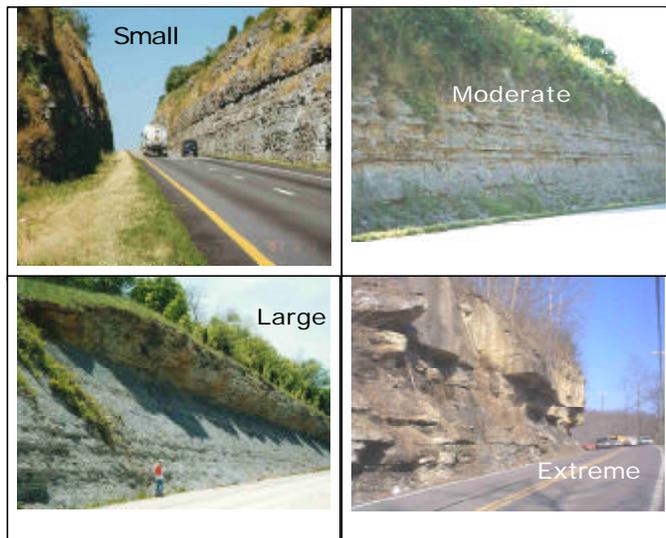


Figure 62. Rock slopes with different degrees of differential erosion rates.

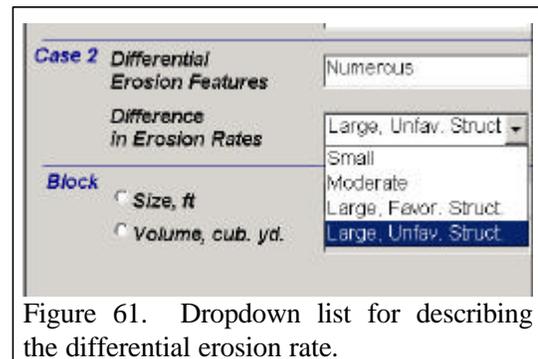


Figure 61. Dropdown list for describing the differential erosion rate.

largest dimension in feet of rock (Figure 51). The category score is simply a function of the size of the block, as illustrated in Figure 63. If **Volume**, as illustrated in Figure 64, is the determining factor, such as a pile of rocks instead of a few or several scattered individual rocks, click the **Volume** button and enter the

approximate volume of material in cubic yards, which has fallen, or has the potential to fall. The

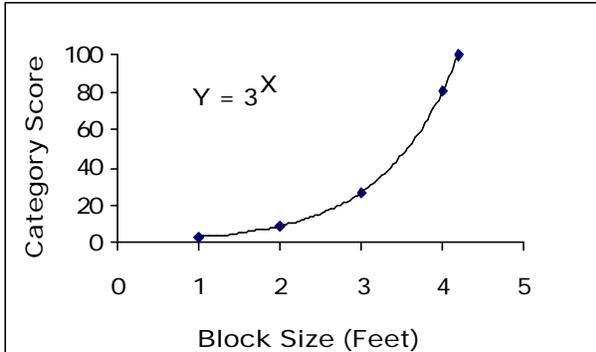


Figure 63. Category score as function of block size.



Figure 64. Illustration of rock fall volume.

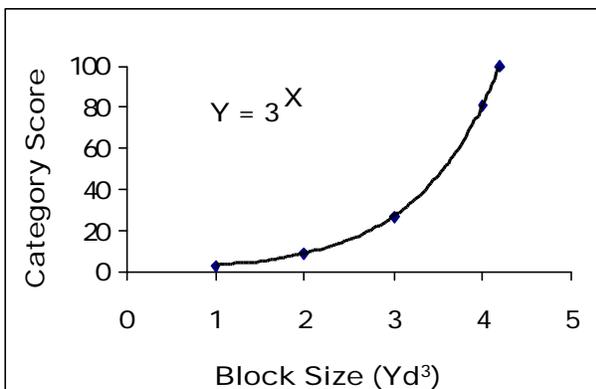


Figure 65. Category score as function of volume of fallen rock.

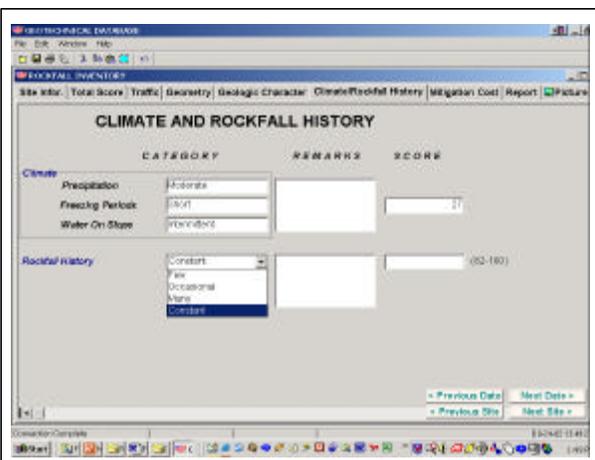


Figure 67. GUI screen for entering climate/rockfall history data.

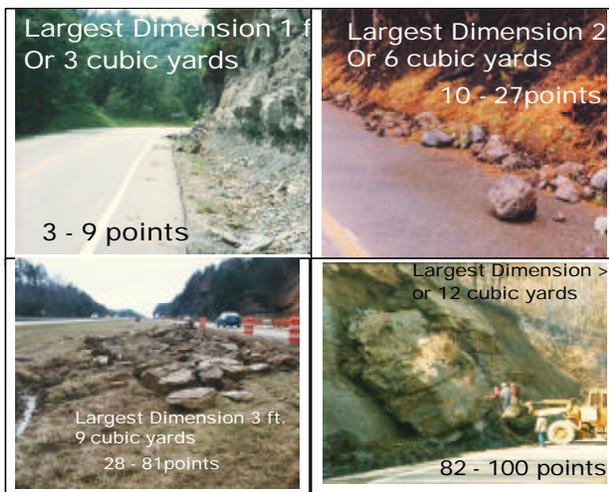


Figure 66. Category scores for example rock slopes with different Block/volume dimensions.

SCORE will be automatically entered based upon volume. The relationship of category score and volume of material is shown in figure 65. Rock slope scoring examples with different block or volume dimensions are depicted in figure 66.

By clicking the tab, identified as **CLIMATE/ROCKFALL HISTORY**, in Figure 29, a GUI screen for scoring the climate and the rock fall history is enabled, as shown in Figure 67. Climate: RHRS was developed by the Oregon Department of Transportation. Oregon has many different climatic conditions. The scoring conditions were based on Oregon’s climate. Climatic conditions are described elsewhere (Pearson and Vickle 1993).

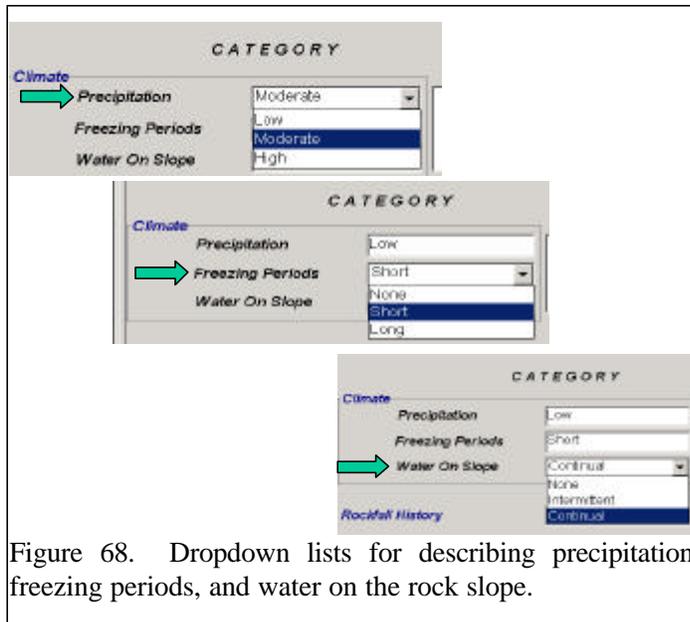


Figure 68. Dropdown lists for describing precipitation, freezing periods, and water on the rock slope.

Climate score is based on the amount of precipitation, free-thaw cycles and water on the slope. Typically a score of 27 is used for Kentucky because Kentucky’s precipitation and freeze thaw periods are fairly uniform statewide. The score may be changed if the rater is supplied information concerning the slope, such as the amount of water present.

Precipitation: This parameter is selected from a dropdown list, Figure 68. The user may describe the precipitation as **Low**, **Moderate**, or **High** from the drop down list or type the first letter of the selection. **Freezing Periods:** select **None**, **Short**, or **Long** from the drop down list, Figure 68, or type the first

letter of the selection. **Water on Slopes:** select **None**, **Intermittent**, or **Continual** from the drop down list, Figure 68, to make a selection or type the first letter of the selection.

CLIMATE is scored as follows:

If **Precipitation, Low to Moderate**, and **Freezing Periods, None**, and **Water on Slope, None**, are selected enter a corresponding **SCORE** from 0 to 9.

If **Precipitation, Moderate**, and **Freezing Periods, Short**, and **Water on Slope, Intermittent** are selected enter a corresponding **SCORE** from 10 to 27.

If **Precipitation, High** and **Freezing Periods, Long**, and **Water on Slope, Continual** are selected enter a corresponding **SCORE** from 28 to 81.

If **Precipitation, High**, and **Freezing Periods, Long**, and **Water on Slope, Continual** are selected enter a corresponding **SCORE** from 82 to 100.

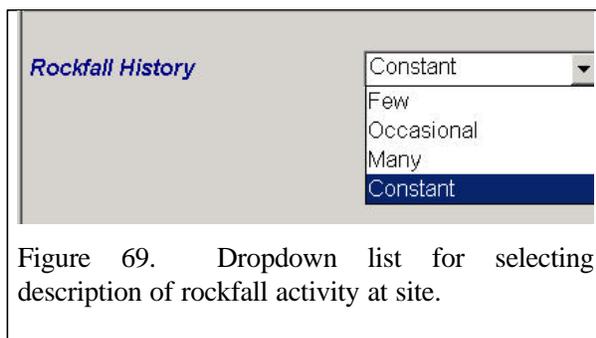


Figure 69. Dropdown list for selecting description of rockfall activity at site.

Because the temperature and rainfall across Kentucky is fairly uniform, a **SCORE** of 27 is suggested for all rock slopes rated in Kentucky.

Rock fall History: This parameter is scored by selecting **Few**, **Occasional**, **Moderate**, or **Many** from the drop down list, as shown in Figure 69. The best source of Rock fall History is County and District Transportation Cabinet, Operations Personnel. The category **SCORE** is assigned as follows:

If **Few** is selected enter a corresponding **SCORE** from 0 to 9.

If **Occasional** is selected, enter a corresponding **SCORE** from 10 to 27.

If **Moderate** is selected, enter a corresponding **SCORE** from 28 to 81.

If **Many** is selected, enter a corresponding **SCORE** from 82 to 100.

MITIGATION COST ESTIMATE

Route: Highway District: County:

Location: Date of Rating:

Description: Average Daily Traffic:

Req. MP: Post Speed Limit:

End Mp: Total Score:

Direction: Ctr. Line:

Name of Designer: TL Beckham

Design Option Description: This approach is a correction Design
Trim blast slope to create a 22-foot wide fallout area. Shotcrete lower 15 feet of cut to halt differential erosion. Install Jersey barrier at edge of pavement.

Design Cost Estimate:	Elements	Quantity	Unit	Unit Cost	Cost
1.	Excavation	121,000	cuyd X	\$350	\$423,500
2.	Trim Blasting	70,000	ln#936 X	\$2.00	\$140,000
3.	Shotcrete	27,000	sqft X	\$3.00	\$81,000
4.	Jersey Barrier	1,584	lnft X	\$22.00	\$34,848
5.	Excavation		X		
6.	Artificial Reinforcement		X		
7.	Shotcrete		X		
8.	Barrier Systems		X		
	Drainage		X		
	Trim Blasting		X		
	Jersey Barrier		X		

Total Design Cost: \$679,340
Cost/RHRS Score Ratio: 936

< Previous Date Next Date >
< Previous Site Next Site >

Figure 70. GUI screen for entering estimated remedial methods and costs for correction or hazard reduction plan.

As shown in Figure 70, the **Mitigation Cost Estimate** screen can be used to estimate the cost for repairing a rock slope and compute a cost/RHRS score ratio. Total Design Cost is calculated by selecting elements to be used in the repair from a drop down list and entering the quantity and unit cost for each element. A **Cost/RHRS** ratio is then determined.

When the **Report Screen** (Figure 70) is selected a written report, summarizing all of the attributes and key information of a rated slope, is displayed, as shown in Figure 71.

Visual Features of Database—Electronic Photographs and Map displays

The visual function is an extremely important feature for users. Colored photographs of rock slope and landslide sites can provide valuable visual information. Clicking the mouse on the “PICTURE” tab shown in Figure 70 may access this feature. The GUI screen that appears and an example of a series of photographs of an example rock slope are illustrated in Figure 72. By double clicking the computer mouse on one of the smaller photographs, an enlarged view of the site is obtained, as shown in Figure 73. Attributes can be viewed in photographs that are not necessarily evident in narrative descriptions, or if they could be described, the descriptions would have to be lengthy. Technically, handling visual data in a database is much more difficult

than handling text data because visual data is much greater in size than text data. Because of the size issue, data transmitting speed, processing time, and storage space requirements are primary factors that must be considered. In the early development of the database, photographs were stored as a Bitmap file (a product of Microsoft). The file size was 2.5 Megabytes (Mb). By

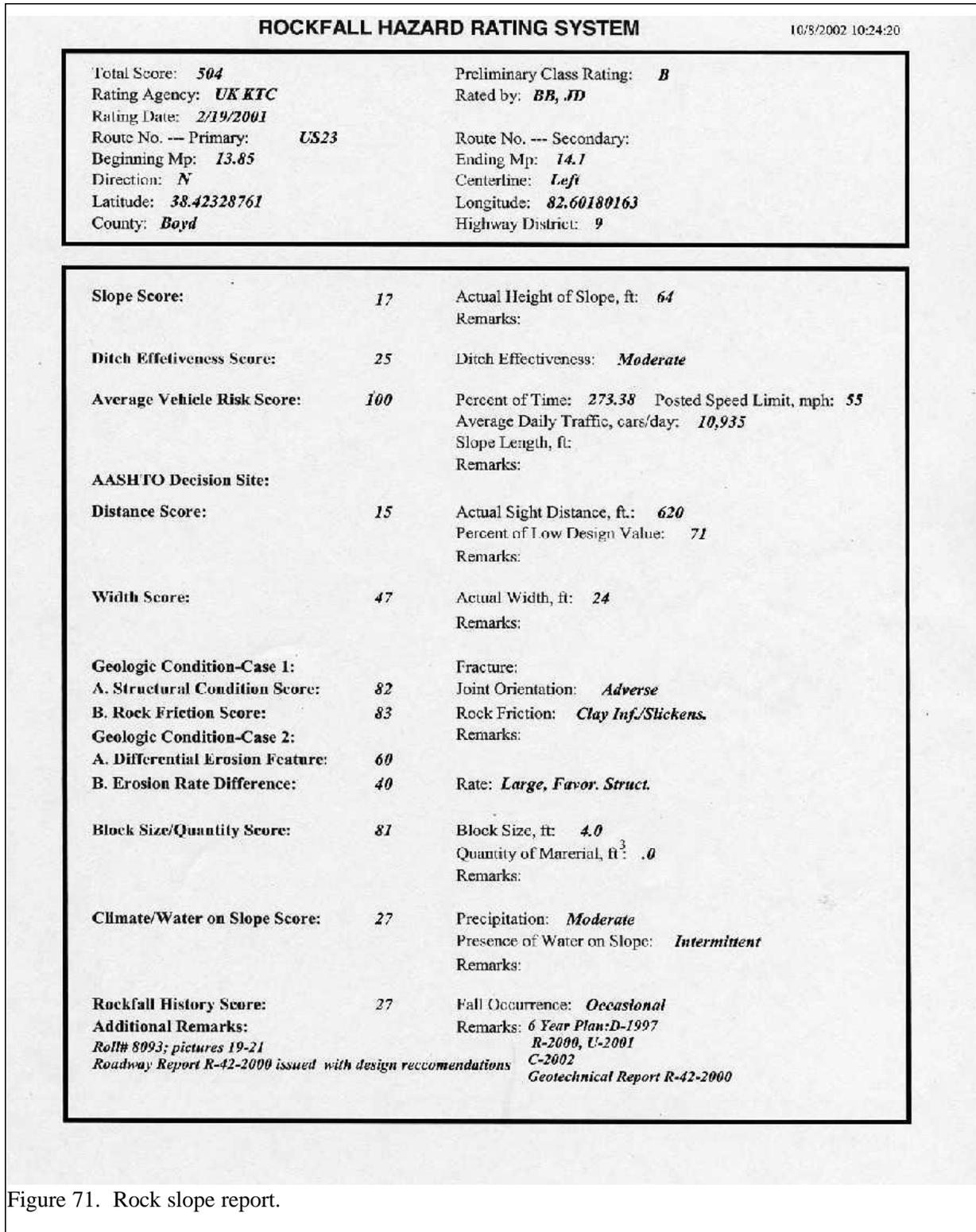


Figure 71. Rock slope report.

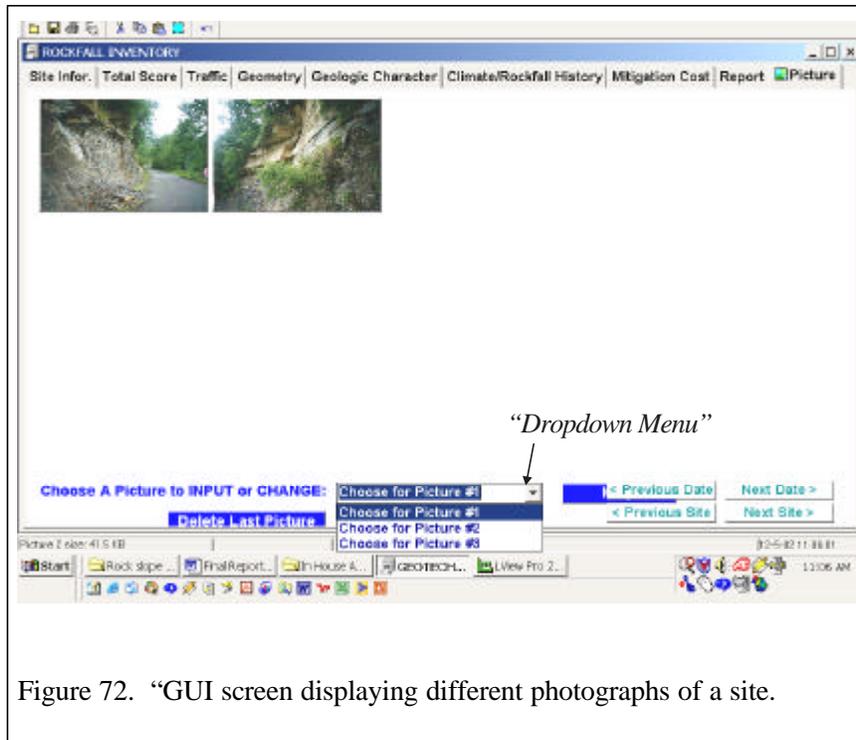


Figure 72. “GUI screen displaying different photographs of a site.

saving the electronic file photographs in a JPEG format, the file size was reduced to 44 Kilobytes (Kb) and reduced space requirements. The reduction was made feasible by algorithms developed by the authors.

Electronic images are entered using the function entitled “Choose A Picture to INPUT or CHANGE,” as shown in Figure 73. To enter a picture, select from a dropdown menu (bottom of Figure 73) “Choose for Picture # n (where n = 1, 2, 3, 4....).” If n is less than or equal to the existing picture number you will need to

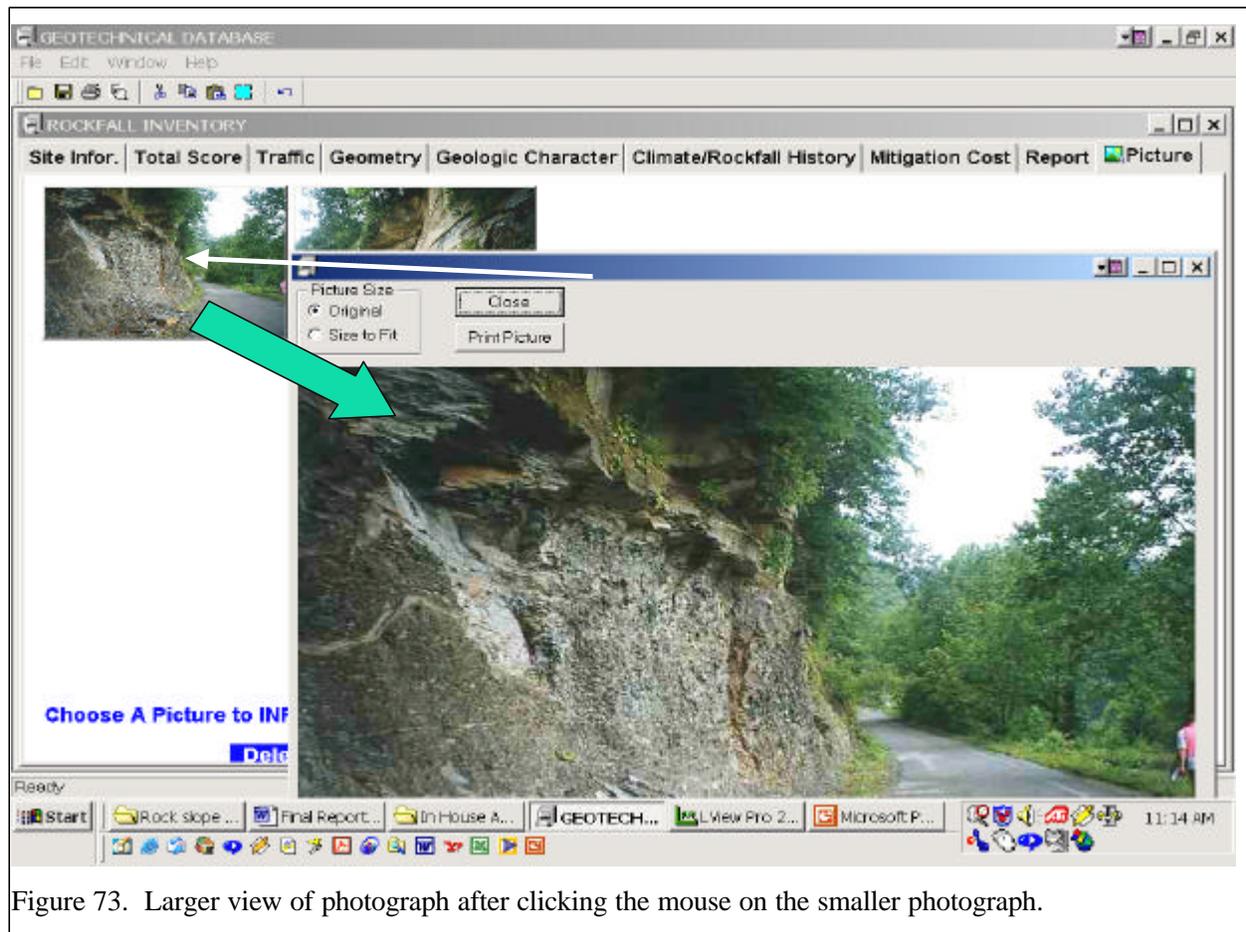


Figure 73. Larger view of photograph after clicking the mouse on the smaller photograph.

change the number to the next larger number to enter a new picture. A box will appear in the upper left hand corner of the screen. Select the drive and directory the electronic images are stored in. Click the mouse on the name of the image to be stored. The image will appear. Adjust the size of the image if necessary to view the entire picture. Images are usually 100% or larger. Reducing the image to about 50 % will allow a full view of the picture. The name of the image will appear in the *Select any File in the Directory to Open It* screen. Click on **Open** and the image will appear on the screen. A **Save Picture** button will appear on the picture input screen. Click **Save Picture** and image will be saved to the database. Repeat the process (except *Choose for Picture # 2, 3, 4...*) to install up to twelve (12) pictures per site. The image will be saved as

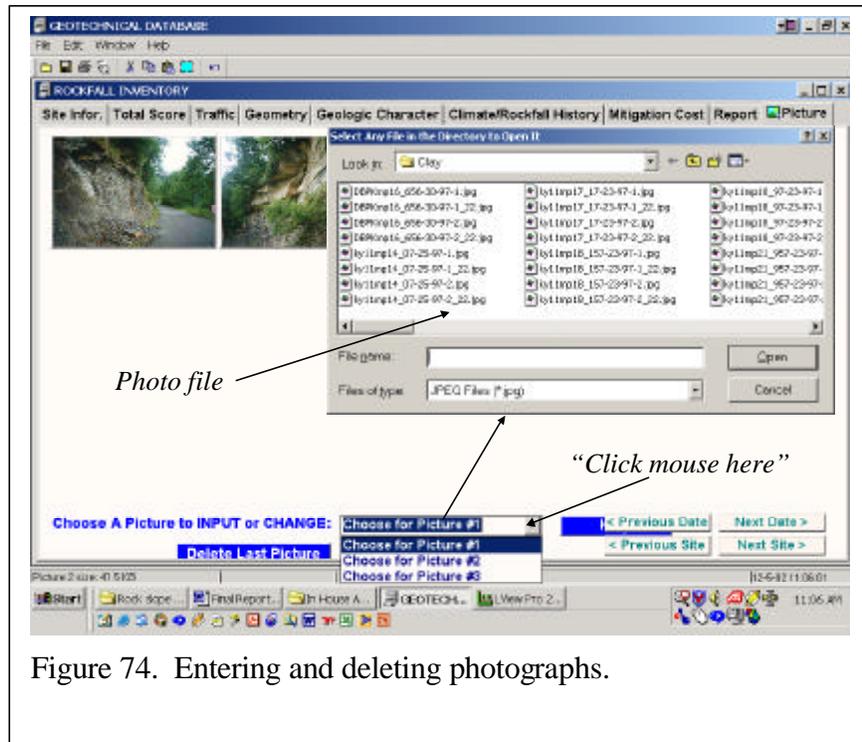


Figure 74. Entering and deleting photographs.

Picture #1. Currently, all images stored in the database are in a *.jpg format reduced to 22% of their original capacity to conserve storage space. Clicking on the button **“Delete Last Picture”** (Figure 74), the last picture will be deleted. Pictures must be deleted from last to first. For example, if four pictures are stored and the second image needs to be deleted, then picture numbers four and three would have to be deleted first. Picture associated with the site can be viewed in a slide or thumbnail format. Double clicking on any slide will enlarge the picture to full screen size and return a screen (Figure 73), which allows the user to “Size to Fit” and “Print Picture” option.

Currently, there are about 5,200 photographs (of landslide and rock slope sites) in the Kentucky Geotechnical database. Other visual images embedded in the database include 120 county maps showing major highway routes of Kentucky. By using MapObject® software, processing speed for displaying maps is extremely fast, and maps can be displayed almost instantly. Moreover, locations and distributions of hazardous rock slopes and landslides, as illustrated in figure 75, can be displayed on roadways of the embedded maps, since latitude and longitude of each site were obtained using GPS equipment. A zoom feature (Figure 75) is included for enlarging viewing areas for details.

The user can click on a boring location and a plot of the boring showing soil classification (as function of depth or elevation) is graphical displayed. Merely pointing and clicking the mouse can identify any roadway on the map. When a rock slope location on the map is clicked, the user is switched to detailed information, and visa versa. A limited number of digitized geological

quadrangles have been embedded in the database (the Kentucky Geological Survey has a program to digitize all geological quadrangles of Kentucky).

General Characteristics of Rock Slopes in Kentucky

In the Oregon DOT and FHWA rock slope hazardous rating system, rock slopes are initially assigned to three categories. If the slope is considered very hazardous, then it is given a preliminary rating of “A”. If the reviewer is not sure regarding the hazardous nature of the rock slope, or the rater feels that the slope may pose some hazard, then the rock slope is rated as “B”. When it is obvious that the slope poses no danger, the rock slope is assigned to the “C” category. In the second phase, the “A” slopes are numerically rated first and, after this task has been completed, the “B” slopes are numerically rated. The preliminary rating is very subjective in nature and depends mainly on the feelings of the rater regarding the potential for rock fall to reach the roadway. As a means of analyzing the subjectivity of the RHRS approach, the numerical scores of the “A” slopes and “B” slopes were analyzed statistically.

Distribution of RHRS scores of the slopes rated “A” is shown in Figure 76. The mean RHRS score for this group of slopes was about 478. In 67 percent of the time, the rater’s score lies between values of 388 and 568. In 95 percent of the cases, the score ranges from 298 to 658. The mean score of slopes rated “B” was 321, as shown in Figure 77, which was less than the

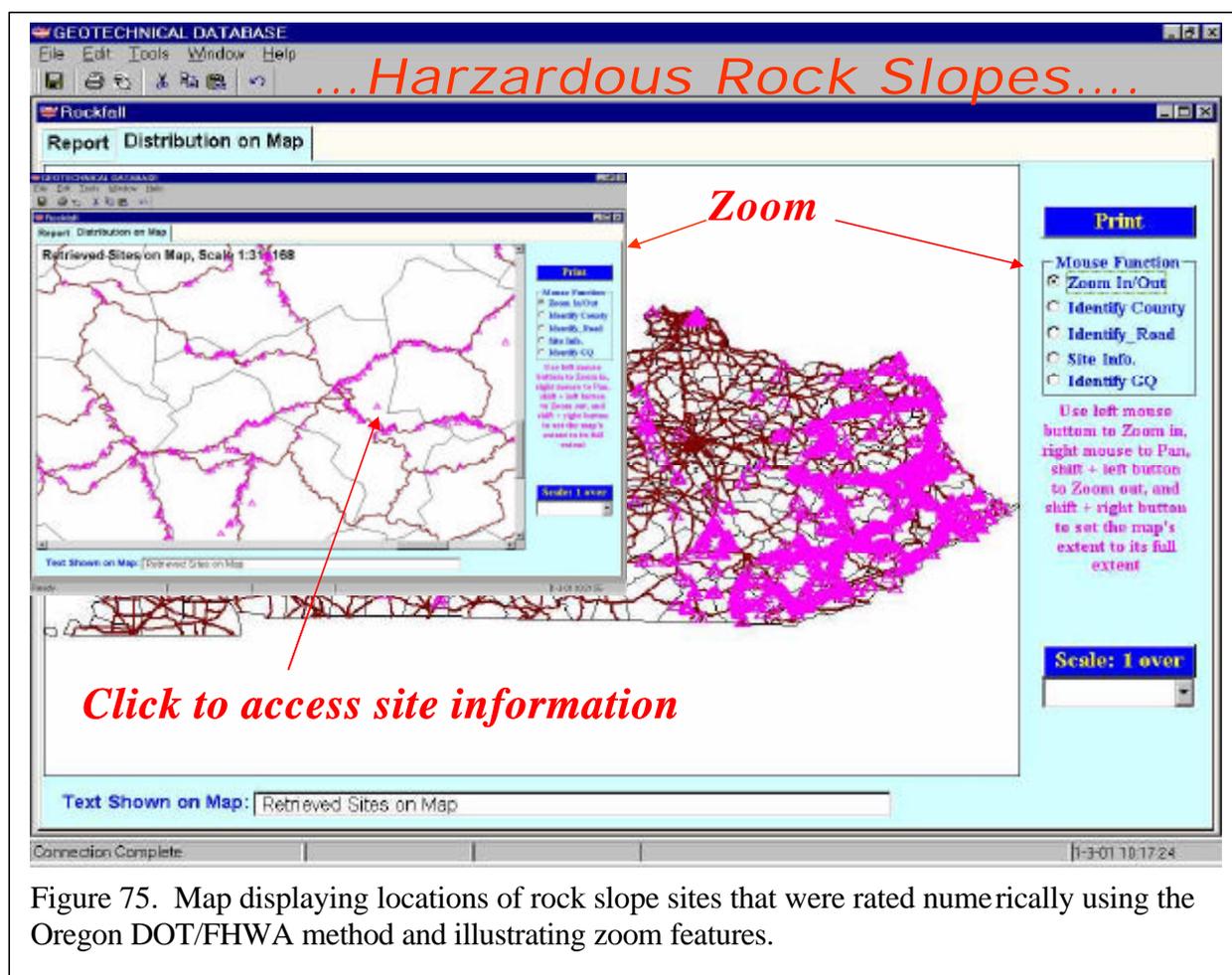


Figure 75. Map displaying locations of rock slope sites that were rated numerically using the Oregon DOT/FHWA method and illustrating zoom features.

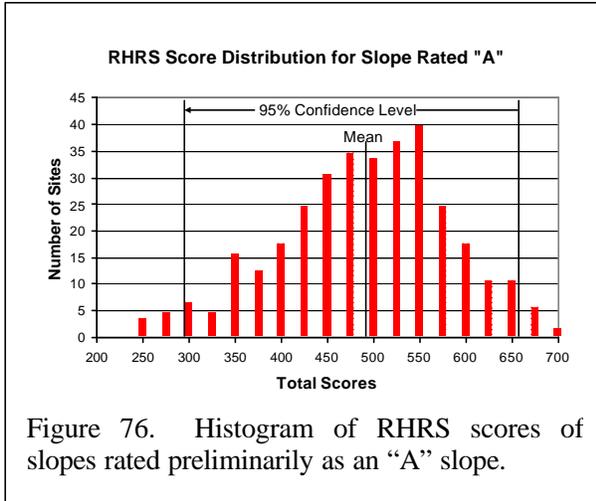


Figure 76. Histogram of RHRs scores of slopes rated preliminarily as an “A” slope.

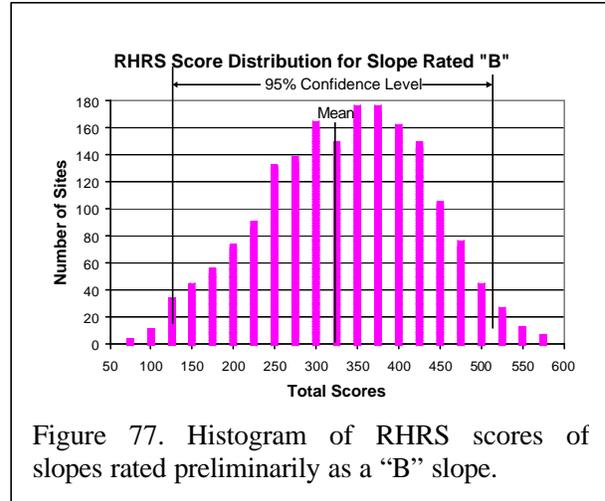


Figure 77. Histogram of RHRs scores of slopes rated preliminarily as a “B” slope.

mean value of the “A” slopes. In 67 percent of the “B” cases, the rater’s score occurred between values of 224 and 418. In 95 percent of the cases, the rater’s score fell in a range of 127 to 515. Generally, numerically scores of the “B” slopes were lower than the “A” slopes. Consequently, the preliminary classification and placement of a rock slope into a subjective category appears to be a very reasonable approach.

As illustrated in Figure 78, about 26 percent (about 1 slope in 4) of the rated highway rock slopes received a rock slope height score (RSHS) of 100 or greater. About 560 rock slopes scored 100. Heights of this category of slopes ranged from about 100 to 368 feet. Distribution of the number of rock slope sites as a function of height of rock slopes scoring 100 is shown in Figure 79. As the height of slope increases, the cost of mitigating, or repairing a rock slope increases. From a future remedial and cost standpoint this may be a significant number. A histogram of RHRs scores when the slope height score is equal to 100 is shown in Figure 80. The mean RHRs score is 410.

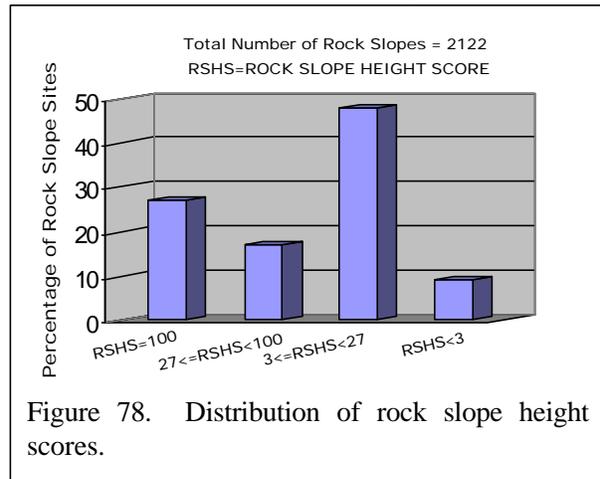


Figure 78. Distribution of rock slope height scores.

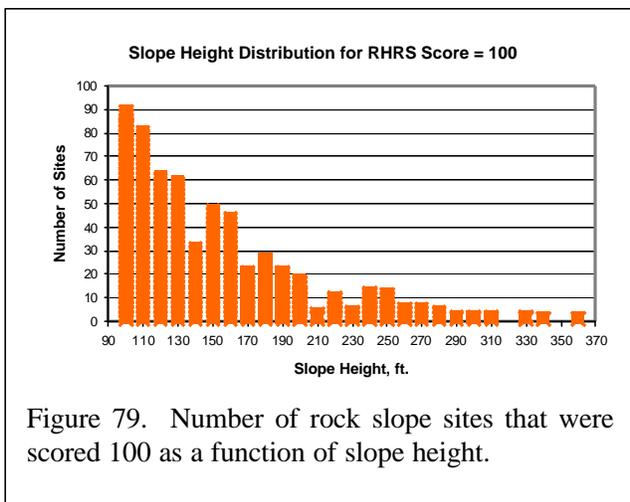


Figure 79. Number of rock slope sites that were scored 100 as a function of slope height.

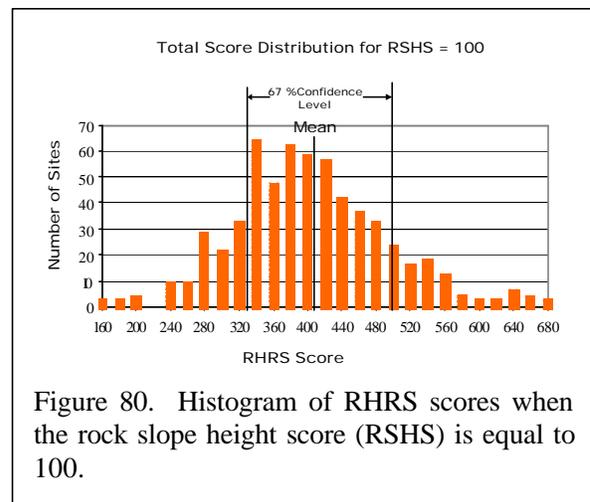


Figure 80. Histogram of RHRs scores when the rock slope height score (RSHS) is equal to 100.

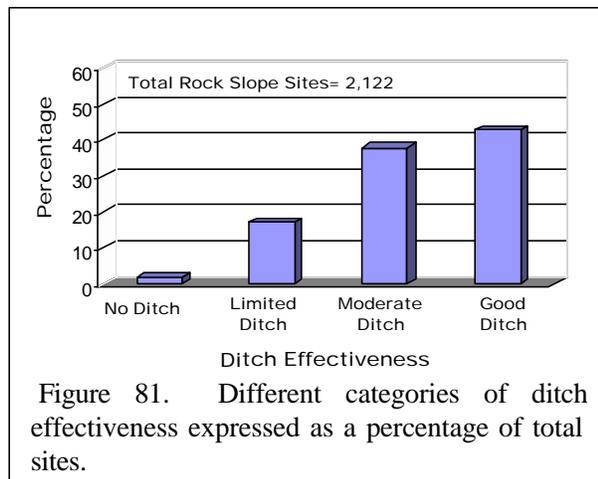


Figure 81. Different categories of ditch effectiveness expressed as a percentage of total sites.

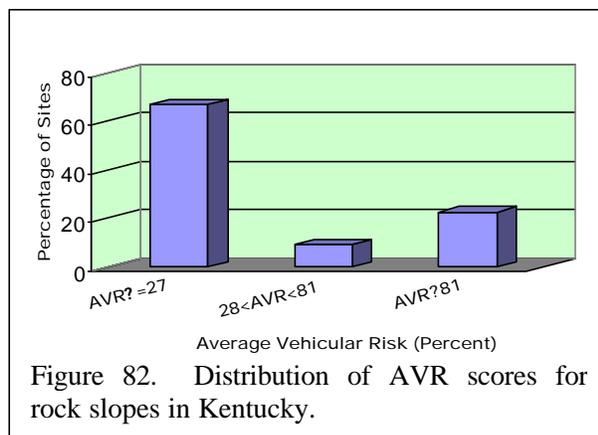


Figure 82. Distribution of AVR scores for rock slopes in Kentucky.

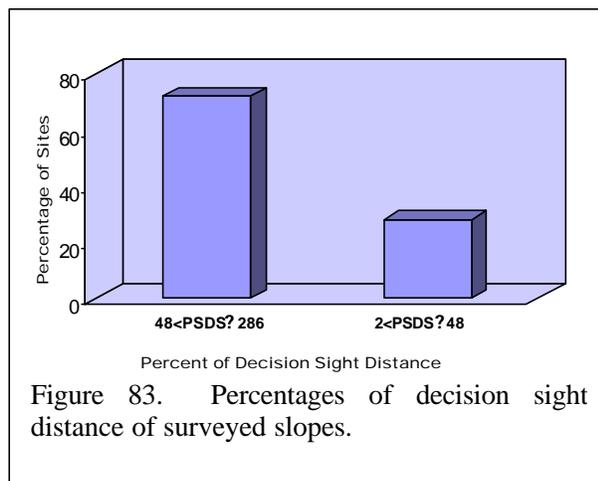


Figure 83. Percentages of decision sight distance of surveyed slopes.

In 67 percent of the cases, the RHRS score ranges from 329 to 491. As shown in Figure 78, in 17 percent of the total observed cases, the rock slope score was less than, or equal to 27 and less than 100. Some 57 percent of the rated slopes were scored less than 27.

To prevent rock fall from entering the highway, it is essential to have sufficient space between the toe of the slope and the edge of pavement, or to have a ditch of sufficient size, to contain the rock fall. As shown in Figure 81, the ditch effectiveness of about 43 percent of the surveyed slopes were rated as “Good.” At 38 percent of the sites, the ditch effectiveness was rated as “Moderate”. In about 19 percent of the cases, the ditch effectiveness was rated as “No Ditch” or “limited”. In about 40 percent of the cases, the effectiveness of the ditch was rated “good” while in 60 percent of the cases the ditch effectiveness was rated “no ditch” to “Moderate”.

The Average Vehicle Risk score determines “the risk associated with the percentage of time a vehicle is in the rockfall section” (Pierson, Van Vickle, 1993). As the value of AVR increases, the risk increases, or the chance that a vehicle may be hit by falling rock increases. As shown in Figure 82, the average vehicular risk, AVR, score of about 67 percent of the rock slopes in the survey was less than or equal to 27. However, the AVR score of about 23 percent of the slopes (about 1 in 4) was greater than or equal to 81.

Another significant parameter in the RHRS system is the percent of decision sight distance. This parameter compares (in percent) the actual sight distance available to a driver to the decision sight decision (prescribed by AASHTO) necessary to avoid hitting an object in the roadway. The larger the value the better

opportunity the driver has to avoid an object in the roadway. The percent of decision sight distance at 28 percent of the sites, Figure 83, could be described as limited to very limited, that is, the sites have limited sight distance.

In the RHRS system, the geology of a rock slope is scored in two different ways. The rock joints are scored (case1) and the erosion of the rock formations is scored (case 2). The largest score of the two cases is used in the total RHRS score. As shown in Figure 84, the rock jointing

case prevailed in 67 percent of the cases. In Figure 85, the distribution of different types of jointing is compared. In 57 percent of the jointing cases, the joint was described as “discontinuous adverse.” When the erosional rate score controlled, the erosional rate was

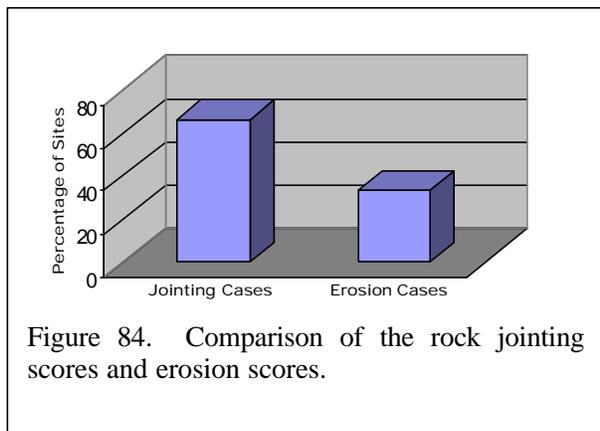


Figure 84. Comparison of the rock jointing scores and erosion scores.

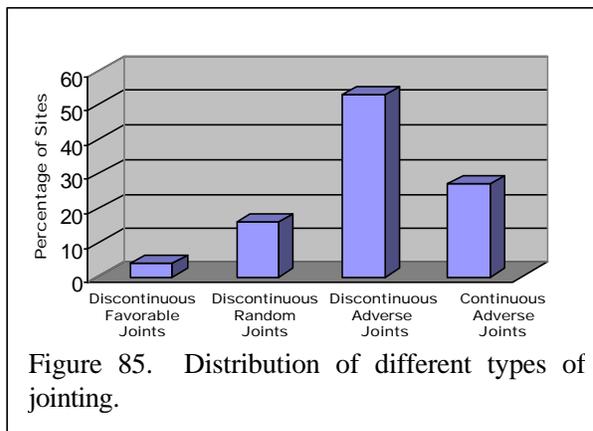


Figure 85. Distribution of different types of jointing.

described as “large and favorable” in 53 percent

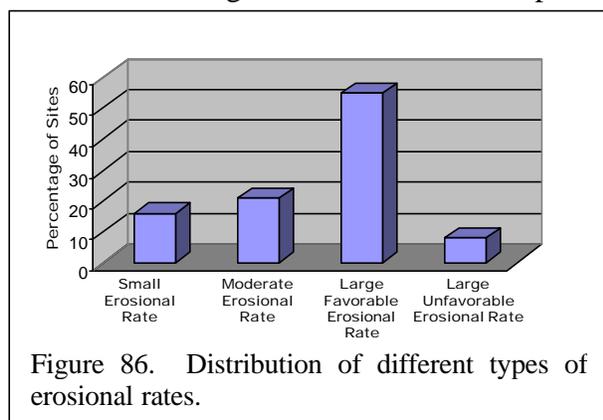


Figure 86. Distribution of different types of erosional rates.

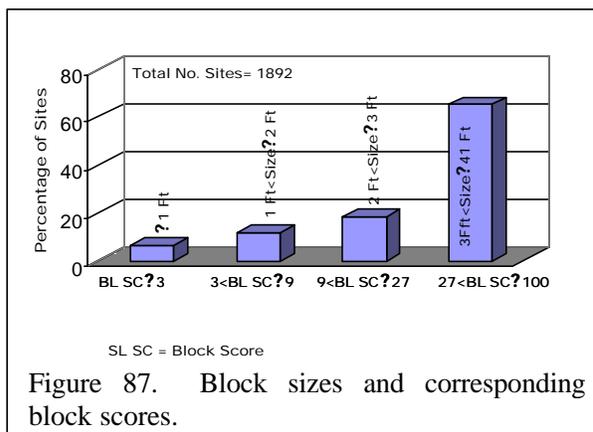


Figure 87. Block sizes and corresponding block scores.

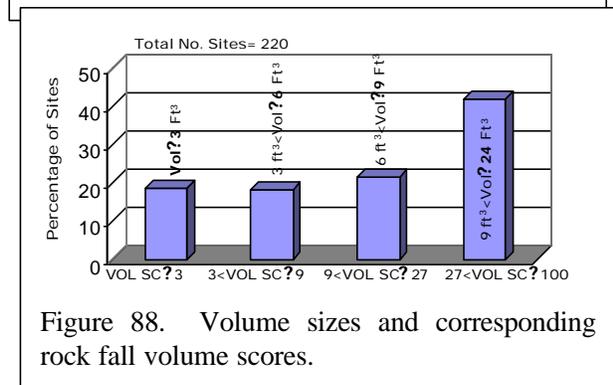


Figure 88. Volume sizes and corresponding rock fall volume scores.

of the cases, as shown in Figure 86.

The size of rock, or the volume of rock fall, that could reach the highway represents a significant danger to the traveling public. Generally, as the rock size, or volume, increases, the danger to motorists increases. The larger the size, or the volume of falling rock to fill the ditch, or area of catchment, and spill onto the highway. In about 60 percent of the observed cases, Figure 87, the block size

was large and ranged from about 3 ft to 41 feet. In about 40 percent of the cases where the size of volume controlled the scoring, the size of volume ranged from about 9 to 24 ft³, as shown in Figure 88. A description of the frequency of rock fall at the surveyed sites is shown in Figure 89. At about 18 percent of the sites (or about 1 in 5), the rock fall history was described as “Constant” or “Many Falls.” As shown in Figure 90, when the total RHRS score is large, the rock fall history score is likely to be large.

Roadway width is another important parameter in the defining the rock fall character of a roadway system. As the width of highway increases, vehicular maneuverability increases and the chances of avoiding rock fall on the highway improve. This condition on the roadway network in Kentucky is examined in Figure 91. In about 38 percent of the cases, the roadway

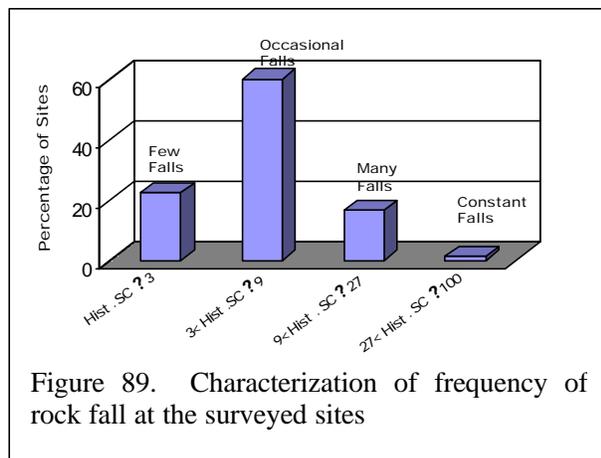


Figure 89. Characterization of frequency of rock fall at the surveyed sites

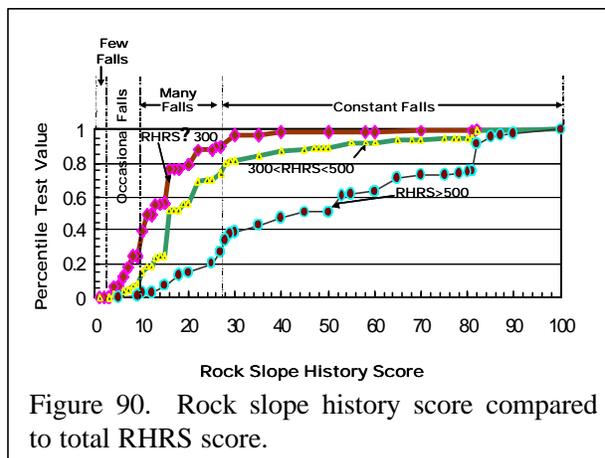


Figure 90. Rock slope history score compared to total RHRS score.

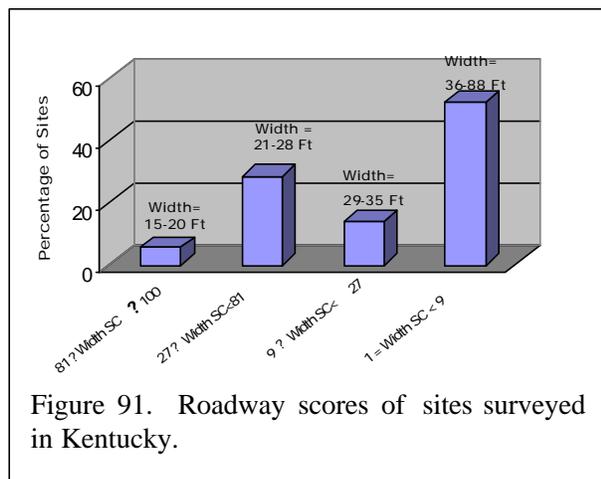


Figure 91. Roadway scores of sites surveyed in Kentucky.

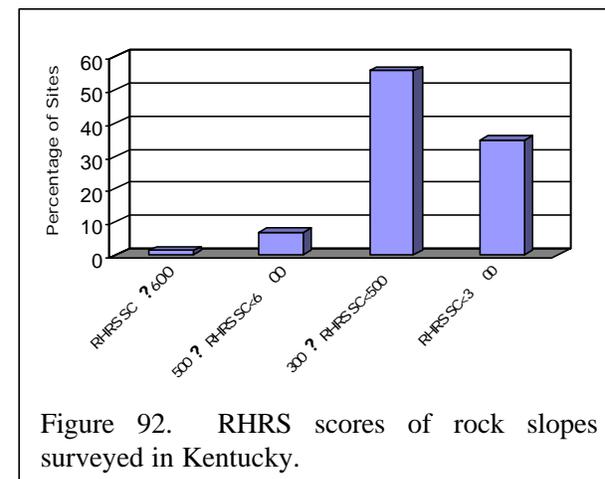


Figure 92. RHRS scores of rock slopes surveyed in Kentucky.

width ranged from 15 to 28 feet. In those cases, the roadway width did not offer much maneuverability.

RHRS Score versus Actual Rock Fall Experience

About 8 percent of the rock slopes in the survey scored 500 or greater, based on the ODOT/FHWA Rock Hazardous Rating System, as shown in Figure 92. The RHRS score of twenty-five of those slopes ranged from 604 to 689. In all of those cases, the rock fall was described as “Many” and “Frequency.” The RHRS score of about 149 rock slopes ranged from a value equal to or greater than 500 and less than 600. The RHRS score of about 1 in 12 sites was equal to or greater than 500. Past experience, although limited, indicate that slopes that are scored more than 500 will probably involve considerable remedial, or mitigation, costs.

A very limited amount of experience is available that for relates the ODOT/FHWA RHRS score and rock fall history. However, a sampling of some of the rock slopes that received very high scores is described briefly below. In four rock slope cases that received the highest

numerical scores in Kentucky, catastrophic, or severe, failure occurred at three of the sites shortly after the numerical ratings were performed. One site, which received one of the highest RHRS scores (689), is shown in Figure 93. Large rocks are shown at the base of the slope. Rock fall at this site scored “Many.” Repairs cost about \$400,000.

Another site (before failure) that was scored 664 is shown in Figure 94. A view of this site after failure was shown in Figure 1. A view of the slope after emergency repairs were made is shown in Figure 95. The Colorado rock fall simulation computer program (Pfeiffer and Bowen 1989; Pfeiffer 1993) was used to develop the emergency design. About \$250,000 was spent in



Figure 93. Large boulders at the base of a rock slope on Ramp A of KY 56 in Webster County—RHRS score equal to 689.



Figure 95. View of rock slope on KY 1098 in Breathitt County after emergency repairs—RHRS score equal to 662.

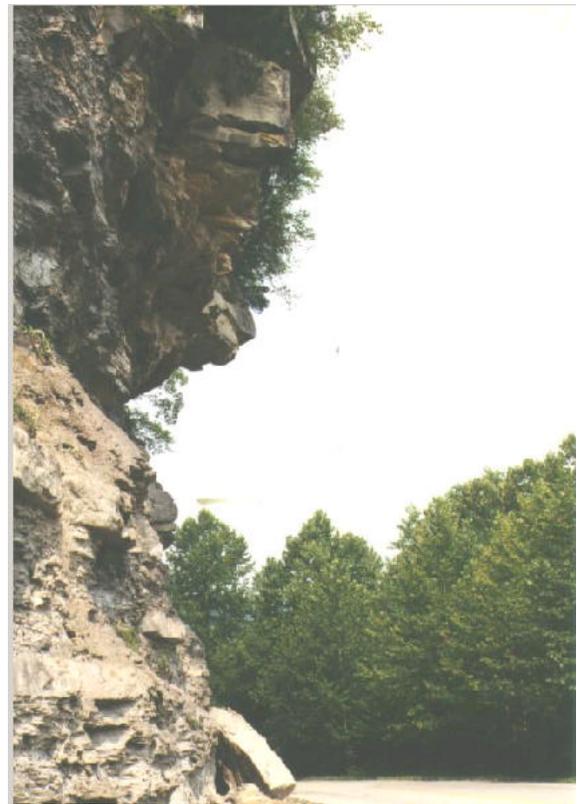


Figure 94. View of rock slope on KY 1098, MP 0.25 to 0.3, in Breathitt County before catastrophic failure.

repairing this slope. The slope after repairs was scored 351.

A third slope where major rock fall has occurred is shown in Figures 96 and 97. This site was scored 662. Numerous rock falls have

occurred at this site as evident from the large scars that are visible on the pavement and reports.

Rock fall at the highest-rated sites has occurred often and “many” times. Size of the rock fall varies from fragments to “car size boulders.” For instance, at one site where the RHRS score was 604, Figure 98, on KY 931 in Letcher County, the rock fall was described in that manner. A major fall occurred on January 27, 2002 and forced the closing of the route until January 30, 2002.

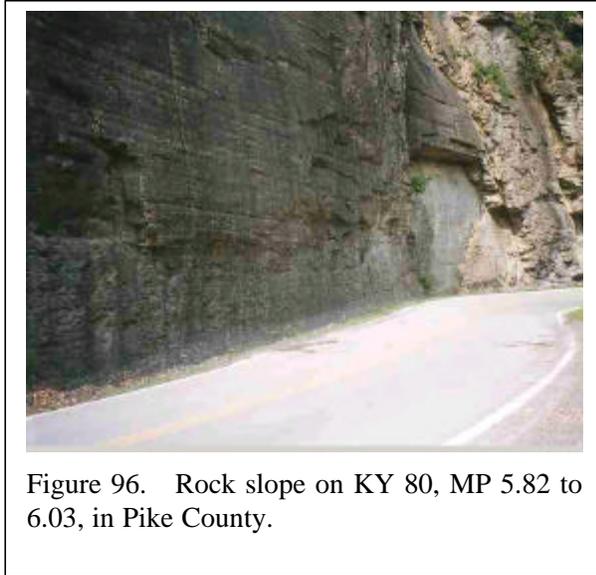


Figure 96. Rock slope on KY 80, MP 5.82 to 6.03, in Pike County.

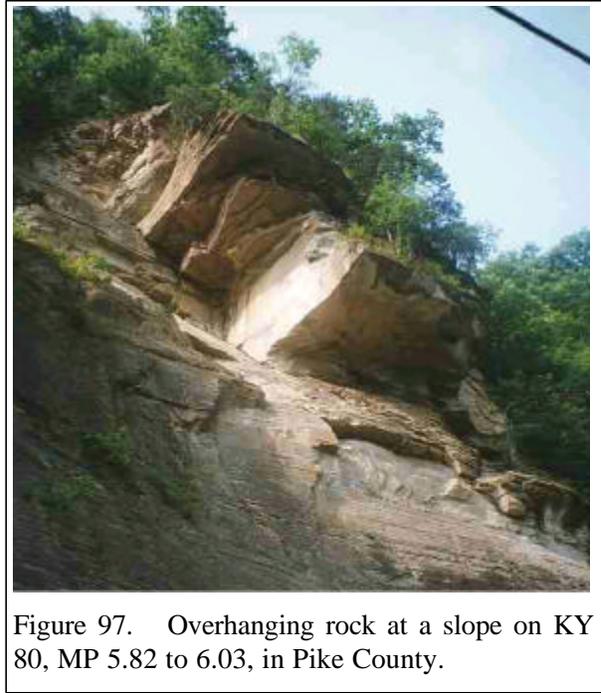


Figure 97. Overhanging rock at a slope on KY 80, MP 5.82 to 6.03, in Pike County.

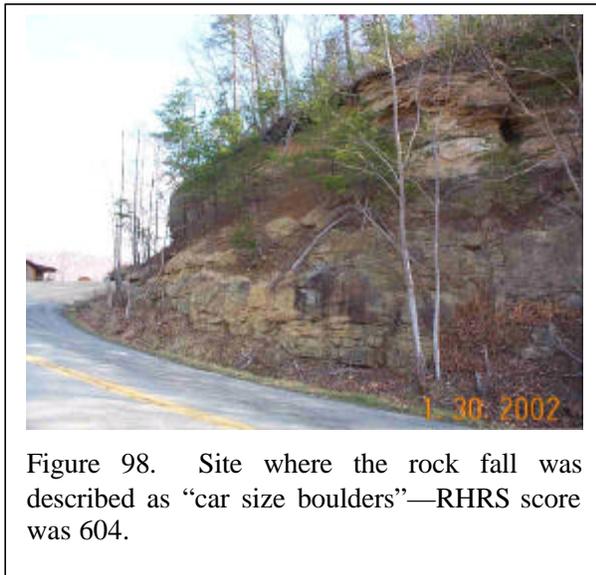


Figure 98. Site where the rock fall was described as “car size boulders”—RHRS score was 604.

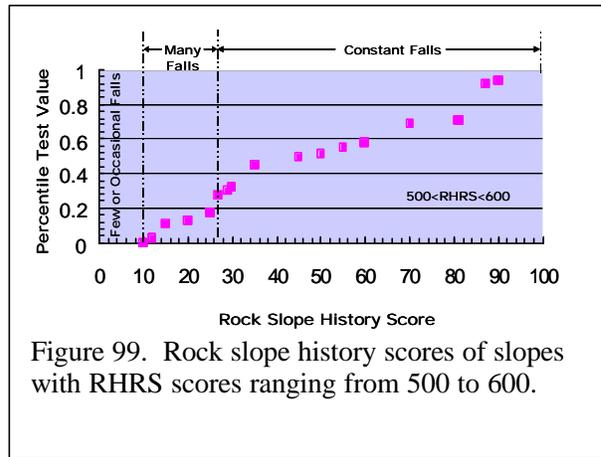
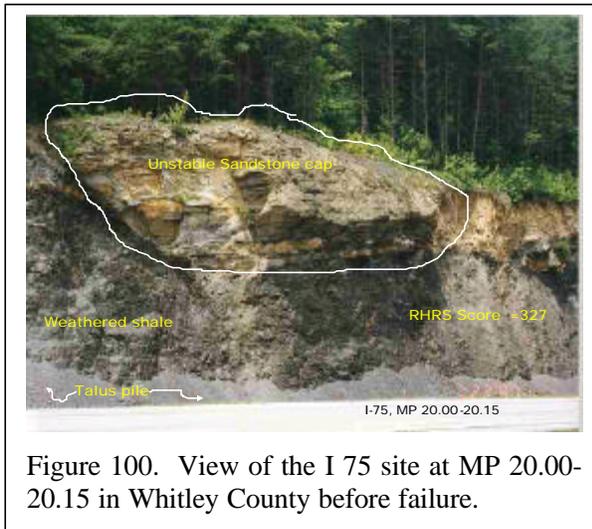


Figure 99. Rock slope history scores of slopes with RHRS scores ranging from 500 to 600.

The rock fall history of rock slopes scoring in the range of 500 to 600 was described as “Many” to “Constant,” as illustrated in Figure 99. For slopes scoring 300 to 500, the rock fall history was described essentially as “Occasional” to “Many,” as shown in Figure 90. When the RHRS score was less than 300, the rock fall history was described mainly “Few” to “Occasional,” as shown in Figure 90.

In the cases cited above, the rock fall and failures are oftentimes related to high values of RHRS. However, one failure occurred in Kentucky that involved a moderate RHRS score of 337. This rock fall occurred on Interstate 75 at MP 20-20.15 in Whitley County. A view of the site, before failure, is shown in Figure 100. On November 11, 2000, massive rock fall occurred, filling the catchment area and spilling onto the southbound lanes. A southbound tractor-trailer struck an approximate 3- to 4- ton boulder and was destroyed in a single vehicle accident. The driver was injured but recovered. Crews were brought in to reconstruct slope the next day. A view of the site the following afternoon is shown in Figures 45, 46, and 47. As shown in Figure

100, talus piles had accumulated at the base of the rock slope. The failure occurred as the result of weathering of shale in the lower part of the slope and the removal of support of the sandstone cap. The talus piles at the base of the slope helped deflect the rock fall onto the southbound lanes. Because this slope was located in long tangent (Figure 45) of highway, had a favorable sight distance, and a wide fall out zone, the RHRS score of the slope was scored lower than in many cases where those factors were unfavorable. However, the large potential overhanging mass still posed a real rock fall danger because it was massive enough to fill the catchment area and spill onto the highway. Cases of this type should be analyzed using the Colorado rock fall computer



simulation program. This example illustrates that the numerical rating of slopes poses a challenge and requires skillful raters. The rater must try to visualize these types of situations. Also, this type of problem aids in gaining experience in using the rating system and points to the need to relate actual experience to the RHRS system.

BRIEF DESCRIPTIONS OF OTHER FEATURES OF THE GEOTECHNICAL DATABASE

Landslide Data and Management System

The landslide data module of the database contains an inventory of landslides that are occurring, or that have occurred, on Kentucky highway routes. The database contains approximately 1300 landslides inventoried by the University of Kentucky Transportation Center and data for about 1,200 landslides imported from a database maintained by the Kentucky Transportation Cabinet. Landslide sites can be sorted according to district, county, route number, and mile point.



Figure 101. Past maintenance activities at a landslide site on US 68 in Mason County.

Landslide slide inventory data was collected using a data format that is used by the Kentucky Transportation Cabinet with some minor modifications. This form was devised from guidelines originally proposed by Hopkins, et al (1988). Information collected for each landslide includes project, site, maintenance history, and severity rating.

Project data includes county, route, milepost, and latitude and longitude. Site information includes the type of slide (embankment or cut slope), height of embankment or cut, length of slide, and a general description of the site. Maintenance data includes average annual daily traffic, maintenance expenditures, and past types maintenance activities, as illustrated in Figure 101.

Landslides are categorized by the following severity descriptions:

- A Very serious--road closed, one lane condition exists, buildings in danger, or safety concern
- B Serious--moving rapidly requiring constant maintenance (daily, weekly monthly, etc.)
- C Moderate movements, breaks in pavement (occurrence over several years)
- D Minor slope failures affecting slope only

Site location and landslide attributes are entered using GUI screens similar to those used for rock fall sites. Additional screens are available for entering maintenance activities and costs, utilities present, adjacent properties and other factors. This format allows easy review of maintenance costs and activities at landslide sites. The main landslide GUI data entry screen is depicted in Figure 102. Details of this portion of the database are detailed in a companion report that is pending.

Figure 102. Landslide data-entry GUI screen.

Structures

Another major component of the database is structures (see Figure 15). Structures include bridges, buildings, culverts, dams, drainage units, pavements, utilities, and walls. Access to and data entry for structures can be obtained using the dropdown list on the site graphical user interface, as illustrated in Figure 103.

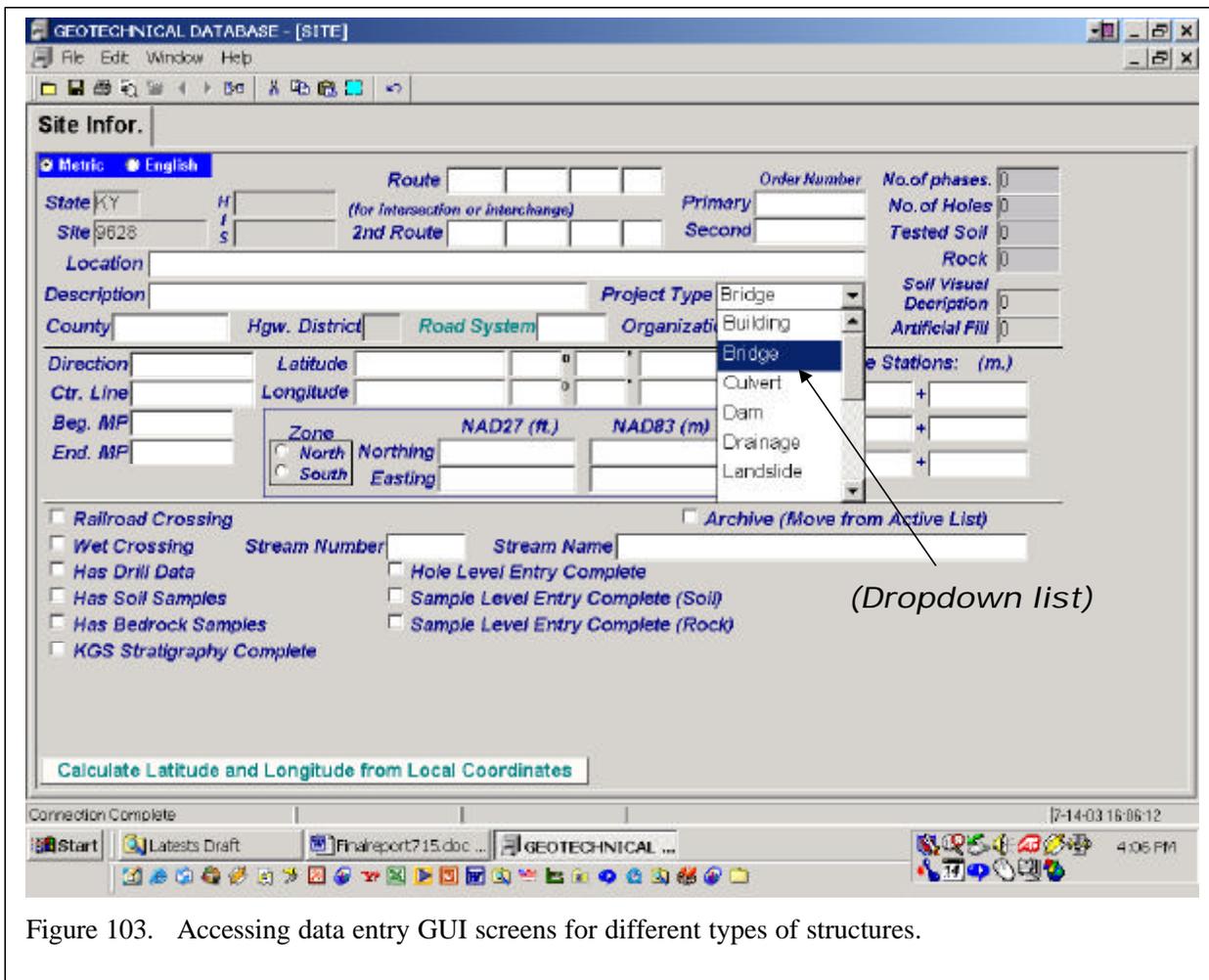


Figure 103. Accessing data entry GUI screens for different types of structures.

Hole, Soil, and Rock Data

Development of this portion of the database consists of two parts. The first portion was designed for entering historical soil and rock engineering data (Figure 104). Soil and rock sample data includes such information as project number, station number, depths, or elevations, of samples, Latitude and longitude, or state plane coordinates, can also be entered. If state plane coordinates are entered, than built-in algorithms automatically convert the values to latitude and longitude. Other sample entries include such data as strength test values, Atterberg limits, grain-sizes, specific gravity, soil classifications, laboratory and field data, bearing ratios, moisture-density relations, Rock Quality Designation (RQD) values, slake-durability indices, jar slake values, soil and aggregate resilient modulus, and consolidation. Hole locations can be retrieved and plotted on maps, as illustrated in Figure 105. Any area on the map in Figure 104 can be enlarged using the zoom feature. By double clicking on a selected hole, a soil profile of the hole is displayed as shown in the figure.

Routines are being developed in the second part of this portion of the database to capture data in a “real-time” mode as the data are initially generated. Procedures for the various geotechnical

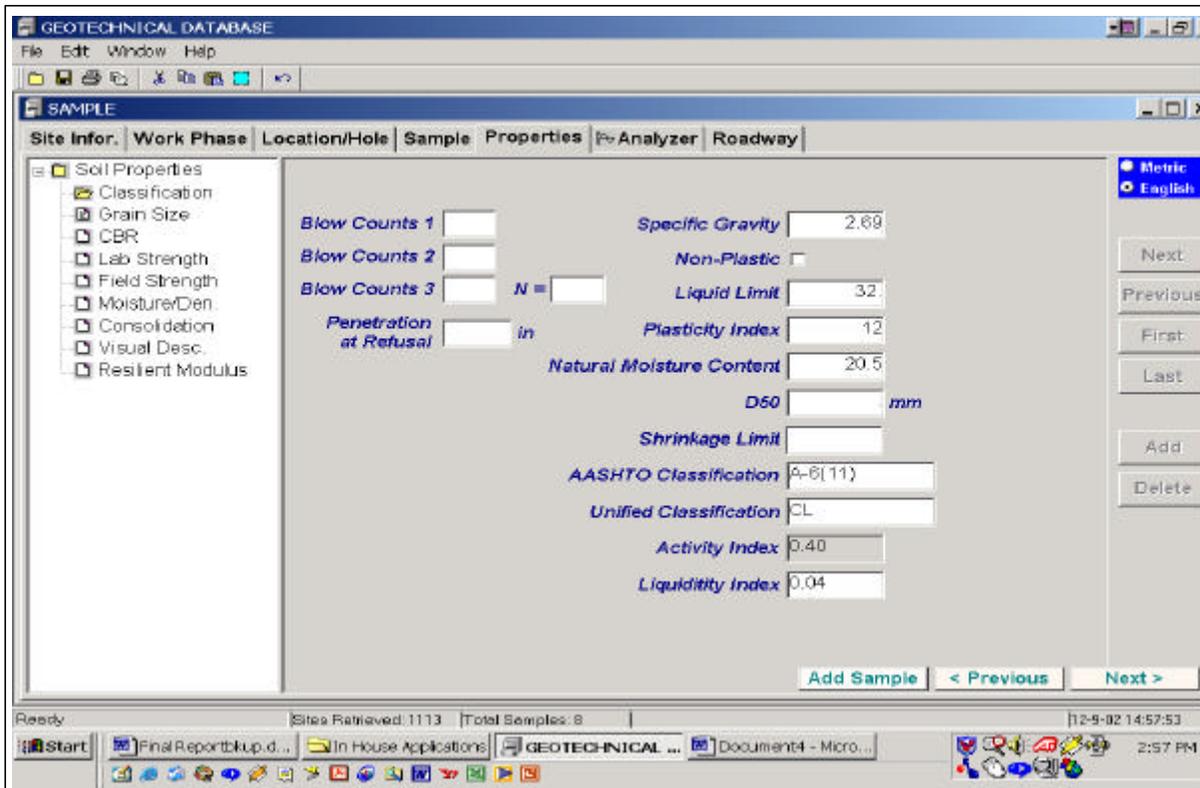


Figure 104. GUI screen for entering engineering and geology data for soil samples and hole data.

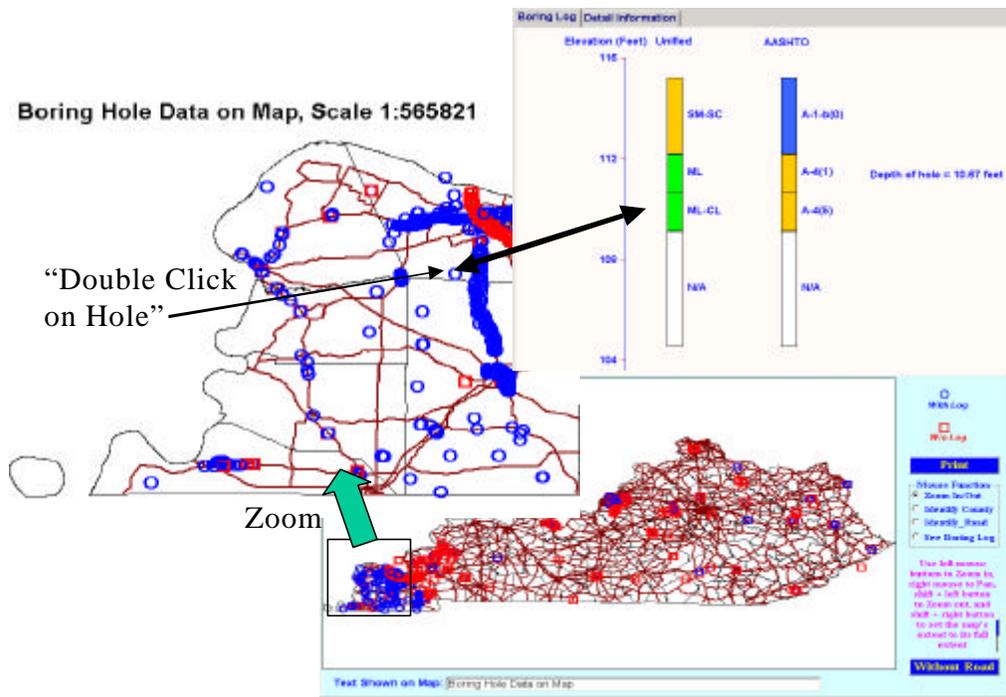


Figure 105. Illustrations of plotted hole locations on a map of Kentucky, the zoom feature, and an example soil profile.

tests are being programmed into the database for entering raw test data. The programmed procedures will automatically reduced the test data and store the essential data into the database. A detailed discussion of this third major component of the database will be described in a future companion report.

Secondary Components

Secondary components of the geotechnical database include a series of statistical and data regression analyzers, engineering software applications, and visual features, which include electronic photographs and map displays. These components have been either been programmed by the authors or other software has been embedded into the database. Another planned secondary feature will allow the storage and reduction of field geotechnical instrumentation data. The secondary components are described in more detail below.

Statistical and Regression Analyzers

To avoid the inconvenience of having to download data to other programs and perform some type of analysis, the database contains a collection of statistical and regression analyzers developed by the authors. These software programs can be used while “on line “ with the database. This feature allows the refining of selected raw data in the database for the purposes of supplying reliable data for preliminary, or in some cases, final engineering designs and for obtaining correlations among different types of data. Functions of this portion of the database analysis are to map out the distributions of all type of data and construct their internal correlation. The results can be presented in both tabular and graphical format.

Currently, data in the Geotechnical Database includes landslide, rock fall, and soil and rock engineering and geologic information. First, programs in the analysis section will present the distribution of those data across the state or any selected and particular location. For instance, data for a highway district, selected county, quadrangle, or other unit area, can be retrieved and analyzed, as shown in Figure 106. In this example, the user is interested in CBR values of soils in a selected highway district in Kentucky. All CBR values that exist in the database for the selected county are retrieved and displayed as a function of percentile test value. For a preliminary pavement design analysis, the user might select the CBR at the 85th percentile test value (Yoder 1969, 1975). Other situations exist where this approach could be useful. For instance, the approach could be used when very small design jobs arise, such as a new ramp off a roadway and it is not very economical to obtain samples for CBR testing. The CBR value at a selected percentile value could be used for designing pavement thickness of the ramp.

Analyzers have also been included in the program for examining the distribution of different soil and rock types, or classes, of a selected area, as well as other engineering properties. Distributions (and statistics) by soil class—AASHTO Soil classifications and Unified Soil Classifications—can be displayed for any selected area, or highway corridor. Knowledge of predominant soil classifications of an area is invaluable for assessing general construction problems that may arise. For example, if the predominant soil classification is known, then the designer, and contractor, can select the most suitable compaction equipment for that area. For preliminary construction cost estimation, this is invaluable.

Secondly, methods for analyzing and disclosing how different types of data are related are included. For example, analysis can present how rock falls and landslides relate to the type of

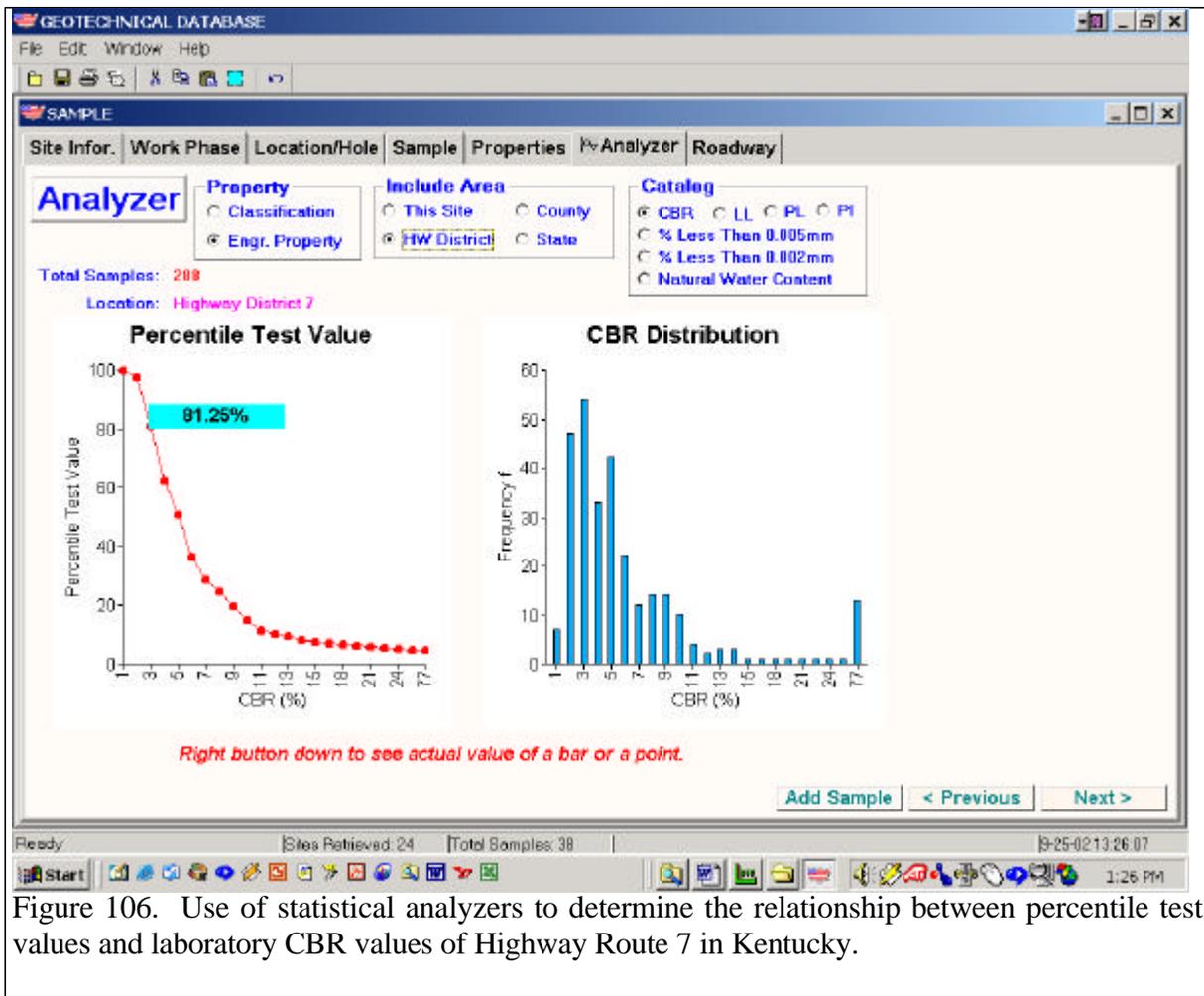


Figure 106. Use of statistical analyzers to determine the relationship between percentile test values and laboratory CBR values of Highway Route 7 in Kentucky.

soil and rock, as well as their properties. Stored regression analyzers yield correlations, or “best data fits,” between different soil parameters. Finally, the large amount of stored data in the Kentucky Geotechnical Database is very useful for research purposes.

Conventional models of stress-strain, consolidation, and modulus-stress will be available for performing data analysis. When choosing any model for soils in a particular location, programmed procedures of the analysis section will show the coefficients for the model selected. For instance, models for predicting the resilient modulus (AASHTO 1992, 1993; SHRP 1989) of any type of soil have been programmed into the database. When the AASHTO soil classification of a soil is known, the resilient modulus can be determined by using the GUI screen illustrated in Figure 107. Various resilient modulus models have been programmed into the database. Included in the models is a model suggested by Ni et al (2002) and Hopkins et al (2002). However, model analysis suggested by Dunlap 1963; Seed et al 1967; May and Witczah 1981; Moossazadeh and Witczah 1981; and Uzan 1985). Both two-dimensional and three-dimensional models have been included in the database. For example, the model proposed by the authors includes two independent variables, the confining stress, σ_3 , and the deviator stress, σ_d , and a dependent variable, the resilient modulus, M_r . A view of the regression plane, based on the authors’ model, for a typical Kentucky soil is illustrated in Figure 108.

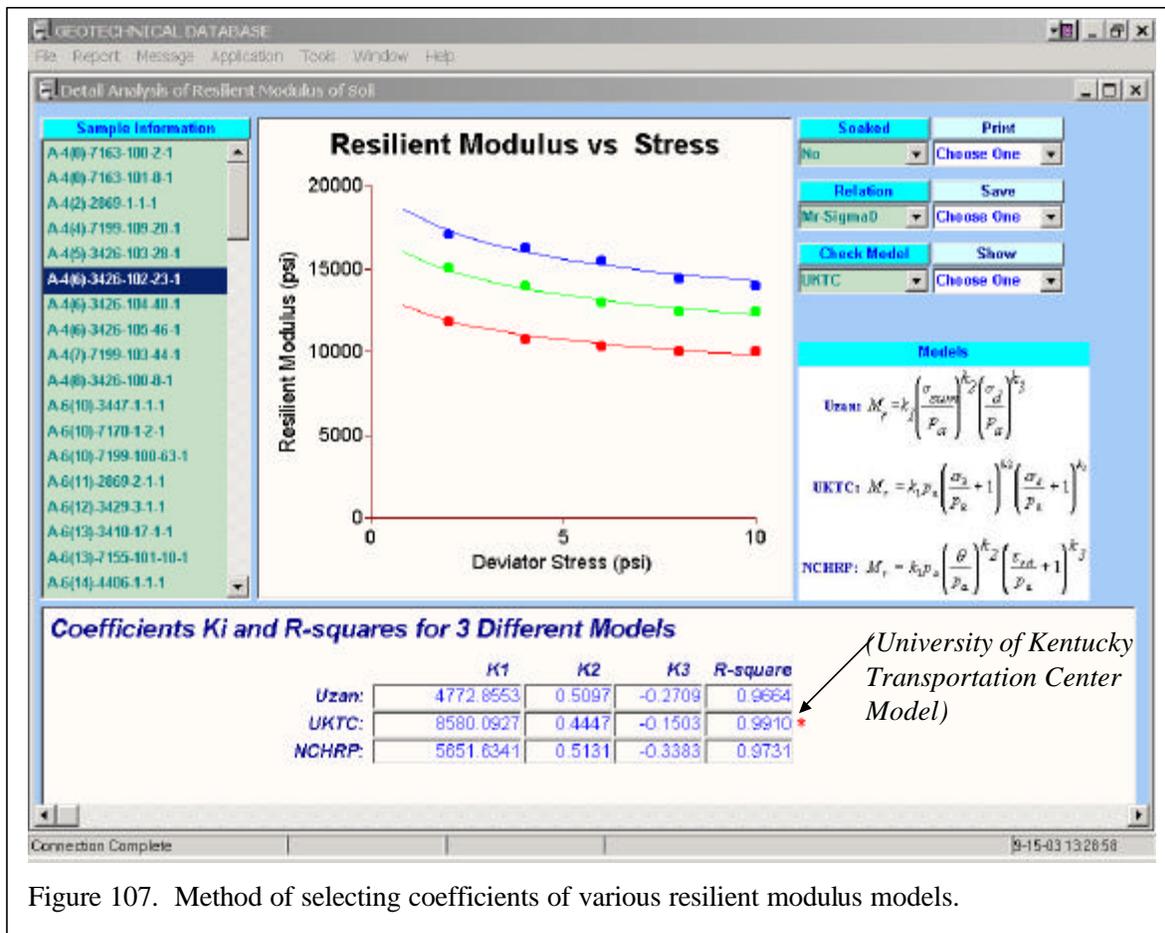


Figure 107. Method of selecting coefficients of various resilient modulus models.

Engineering Applications

Applications in the Geotechnical Database are a collection of computer programs for performing engineering designs of geotechnical structures and for obtaining selected designs in geotechnical engineering. Routine designs such as pavement, foundation, retaining wall, and slope stability are programmed into the Geotechnical Database. In some instances, the programmed computer procedures strictly follow published procedures, standards, regulations, or mathematical algorithms. In other cases, the authors have developed customized computer programs. Examples of programmed procedures and graphical user interfaces include the 1993

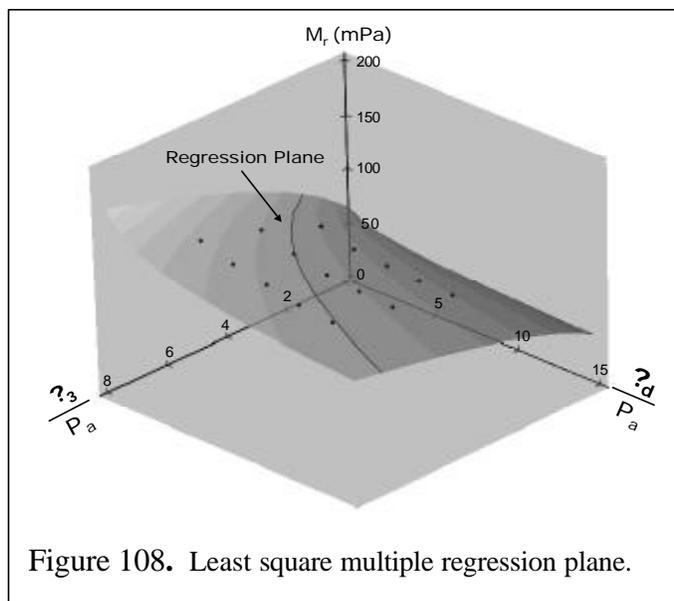


Figure 108. Least square multiple regression plane.

Figure 109. GUI data entry screen for designing the thickness of an asphalt pavement using the AASHTO Design Procedure (1993 Guide).

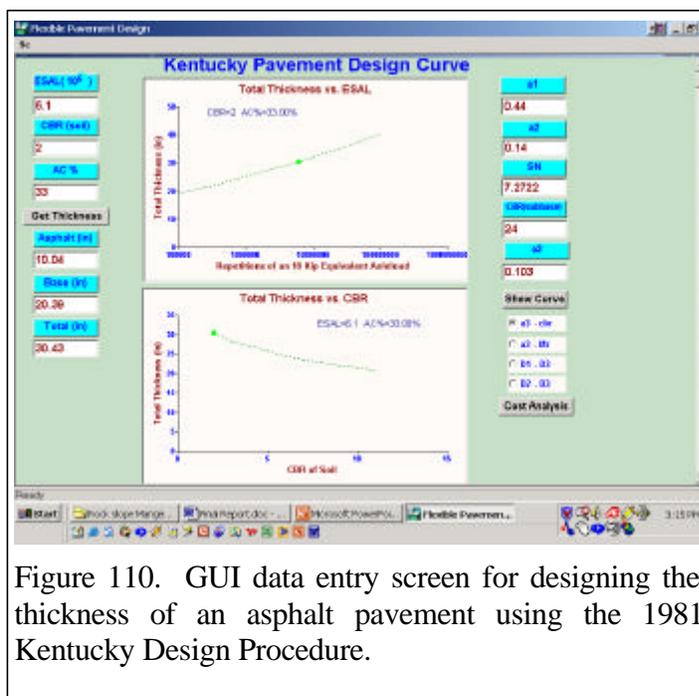


Figure 110. GUI data entry screen for designing the thickness of an asphalt pavement using the 1981 Kentucky Design Procedure.

AASHTO¹ and 1981 Kentucky¹ flexible pavement design procedures, as shown in Figures 109 and 110, respectively. By storing these programs in the database, on-line analysis and designs can be generated. This is very useful in performing preliminary, as well as final designs. The graphical user interface of the computer program illustrated in Figure 110 includes a cost analyzer (Figure 111), which can be used to examine and compare the costs of different pavement design sections composed of pavement layers of different thickness.

Another program in the applications' section of the database can be used to analyze and design retaining walls constructed of driven, or drilled-in railroad steel rails, Figures 112 and 113, and back filled with soil, or lightweight materials. The notion of developing this program for the database occurred after analyzing some 1300 landslides on Kentucky's highways and finding that in at least twenty percent of those cases retaining walls constructed of railroad steel rails had been driven, or fixed into bedrock, in an attempt to halt highway landslide movement. The interactive, data entry GUI screen for determining the factor of safety of a rail piling retaining structure is illustrated in Figure 114. Unit weight of any material may be inserted by merely entering its numerical value. Such lightweight materials as geofoam, "red dog", lightweight aggregate, cinders from coal-fired, power plants may be used in

¹ Computer programs developed by Charlie Sun, Bixian Ni, and Tommy C. Hopkins of the University of Kentucky Transportation Center, Geotechnology Section in 2000.

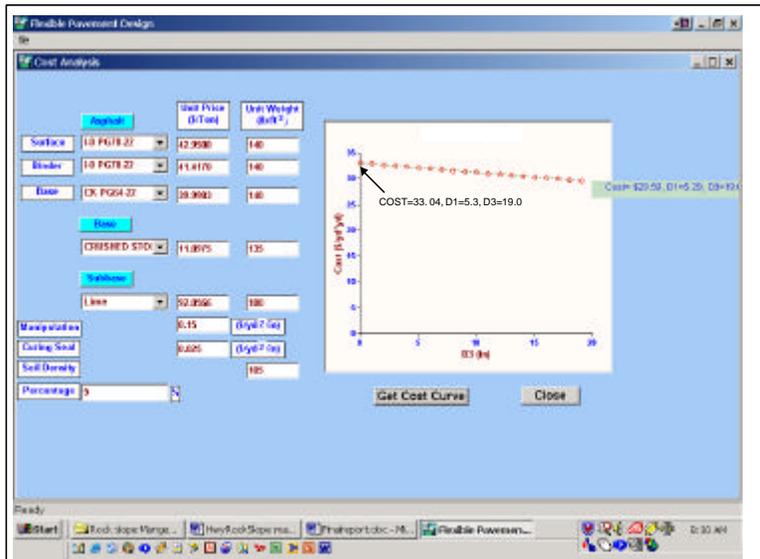


Figure 111. GUI screen for performing cost analyses of flexible pavements with and without chemical stabilization.



Figure 113. Installation in 1998 of railroad rails to form a wall to restrain a hillside landslide. Concrete panels were installed behind the anchored rails. The wall was backfilled with lightweight backfill, which consisted of cinders and shredded rubber tires (After Hopkins, Beckham, Sun, and Butcher 2002).

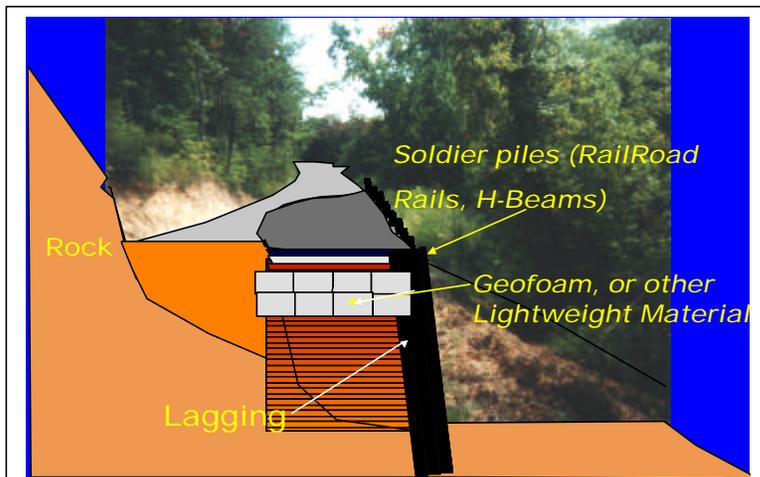


Figure 112. Repairing small highway landslides (20 ft or less) using railroad steel rails (anchored into bedrock) to form a retaining structure and lightweight backfill.

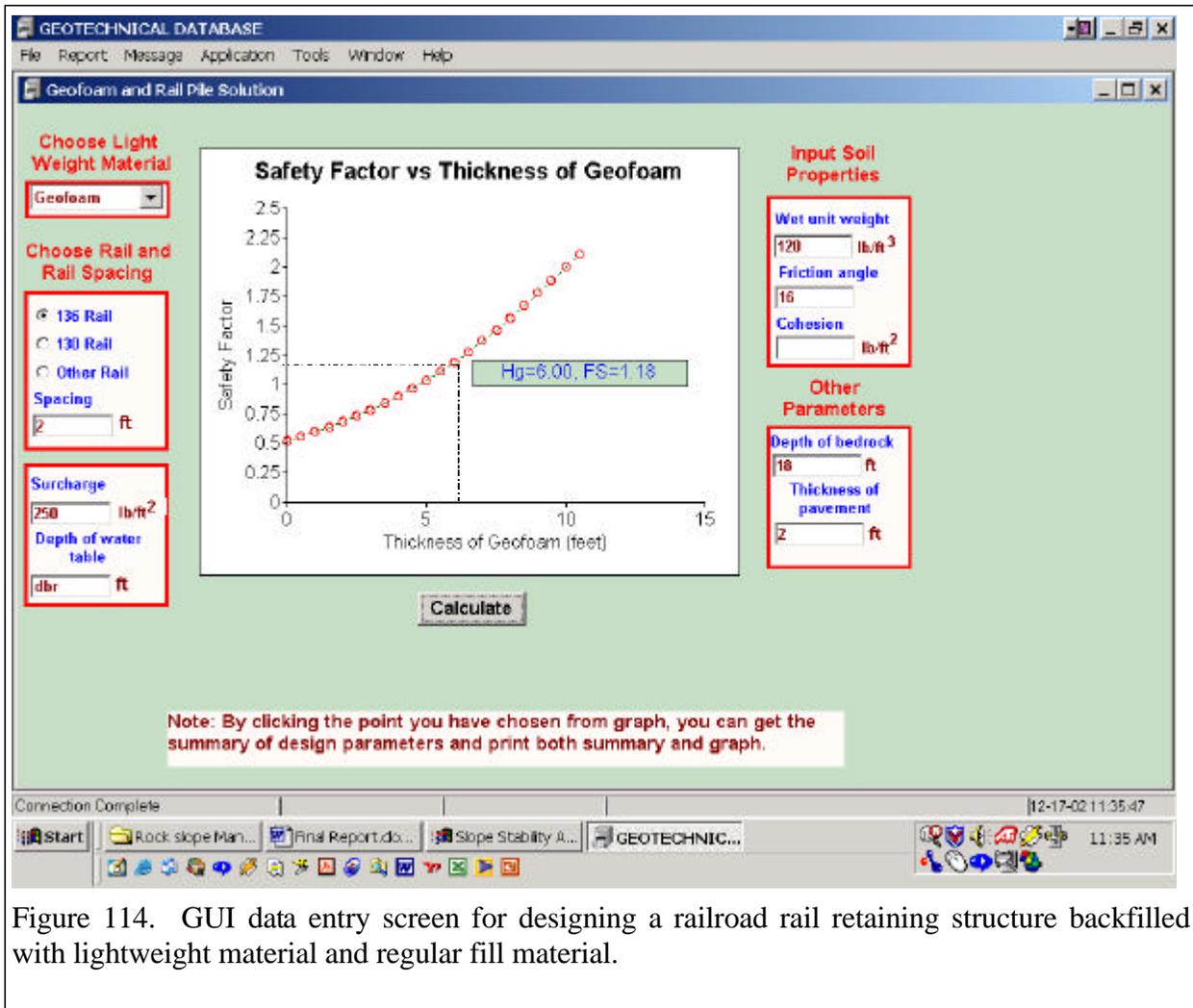


Figure 114. GUI data entry screen for designing a railroad rail retaining structure backfilled with lightweight material and regular fill material.

the program. Algorithms used in the program were derived and developed to account for the use of lightweight backfill materials.

In many cases, railroad rails used as pile retaining structures have not worked. By making a design program available, highway district personnel can quickly develop a proper design for use of this landslide repair technique. In many observed failures, the technique did not work when the backfill was greater than about twenty feet, when the steel rails were not anchored into bedrock, or the soil backfill flowed through the rails. When any of those conditions prevail, state geotechnical engineers do not recommend using steel rail retaining walls. However, the database design program now identifies additional cases where this correction method, which is favored by many district operations (maintenance) offices, might be successful. By using lightweight backfill, and particularly where the rail piling can be anchored into bedrock, slides approaching heights of 18-20 feet, or slightly greater, could be repaired. The amount of lightweight backfill required to achieve a safe design (or a selected factor of safety) is determined from the computer program. District personnel and geotechnical staff of the central office can review the solution simultaneously.

The database programs also provide reports and drawings for all needs of routine sign in the geotechnical field. This will greatly increase the design efficiency, reduce errors, and supply

uniformity. Furthermore, geotechnical staff of the central office can immediately review designs by district personnel and review comments can be transmitted through an internal message exchange channel setup inside the geotechnical database. This is particularly useful when remedial measures may be needed to handle some emergency case, such as a highway landslide. The situation in the field can be sent to the database by digital photographs and cross sections. The state geotechnical and geologist staff can examine and evaluate the situation immediately. Properties of soil and rock in the field can be obtained from the database and used, when available, in the built-in applications to forge a “real-time” decision on the best approach to solving the emergency situation.

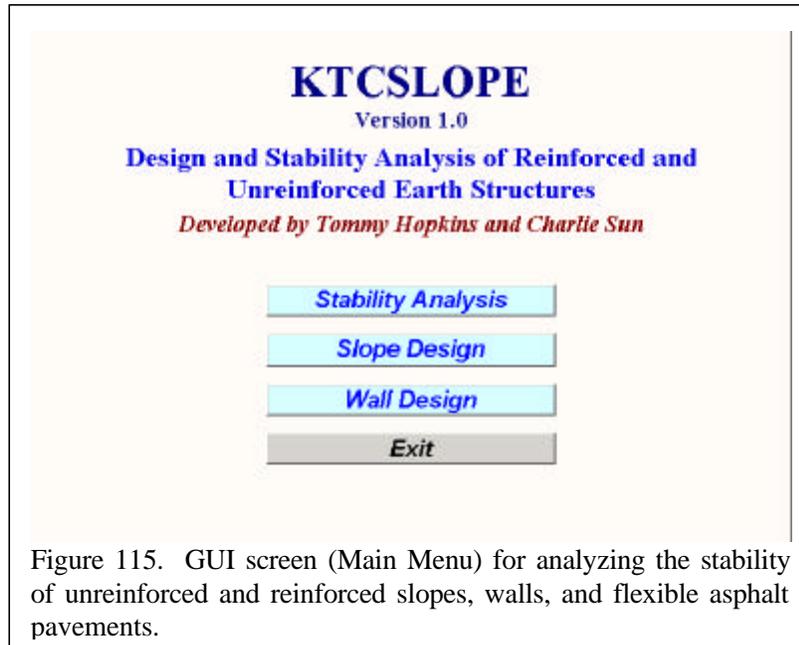


Figure 115. GUI screen (Main Menu) for analyzing the stability of unreinforced and reinforced slopes, walls, and flexible asphalt pavements.

Other computer programs for performing routine analysis and design are continually being added to the applications’ section of the database. For example, a windows-based computer program for analyzing reinforced and unreinforced earth structures (Slepek and Hopkins 1993, 1995a, and 1995b), such as highway slopes and walls has been included. Graphical user interface screens for performing these types of analyses are shown in Figure 115 and 116. Data in Figure 116 shows the stability analyses of a slope using a noncircular shear surface.

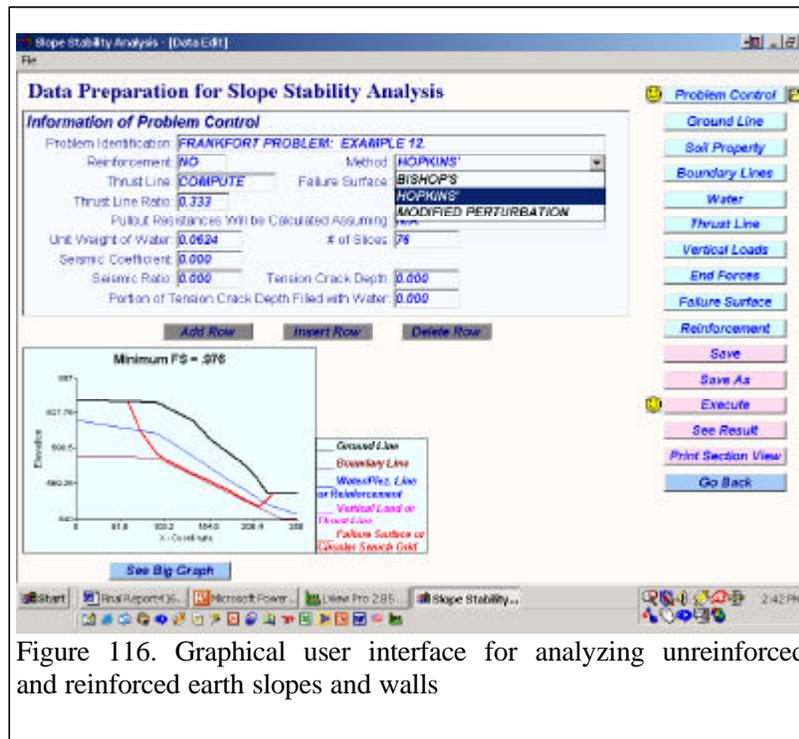


Figure 116. Graphical user interface for analyzing unreinforced and reinforced earth slopes and walls

This software can also be used to perform bearing capacity analysis, or stability analysis, of unreinforced flexible asphalt pavements, or flexible pavements reinforced with geotextiles (Hopkins 1986; Hopkins 1991; Hopkins et al 2002; Hopkins 1994a, b; Slepek et al 1995b; Hopkins et al 2002). Examples of graphical user interfaces for entering data and performing this type of analysis is illustrated in Figures 117 and 118. In Figure 117, the bearing capacity of an unreinforced flexible pavement resting on a soft soil subgrade is

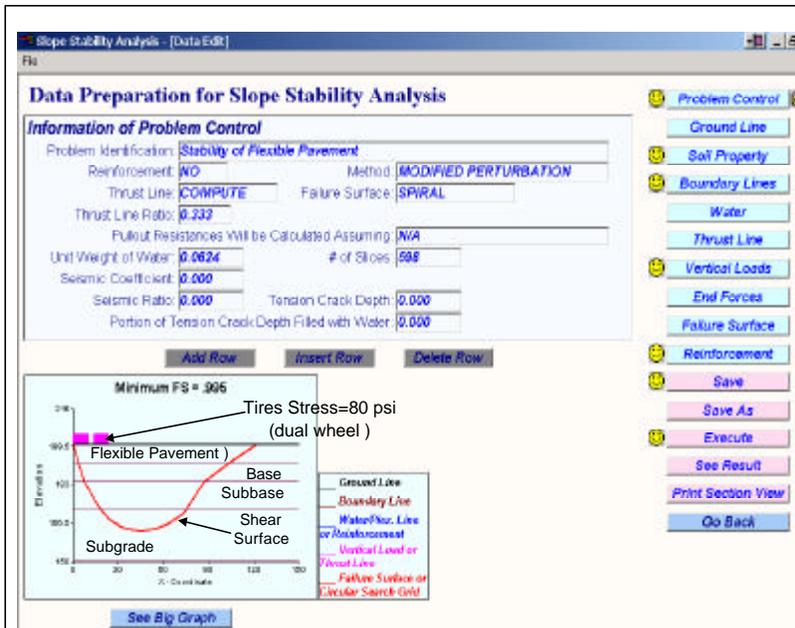


Figure 117. Data entry GUI screen for performing bearing capacity analysis involving flexible pavement multiple layers (unreinforced).

shown. The factor of safety against failure was about 1.00. Using geotextile reinforcement, the factor of safety can be increased to about 1.37.

Software to be included in the database (under development) includes a windows-based computer program for analyzing and simulating rock fall at a selected rock slope site. Other engineering and management software will be added in the future.

Visual Features –Electronic Photographs and Map displays

This visual function is an extremely important feature for users. Colored photographs of highway sites, such as, landslide and rock slopes, can provide valuable visual information. Features can be viewed in photographs that are not necessarily evident in narrative descriptions, or if they could be described, the descriptions would have to be lengthy. Technically, handling visual data in a database is much more difficult than handling text data because visual data is much greater in size than text data. Because of the size issue, data transmitting speed, processing time, and storage space requirements are primary factors that must be considered.

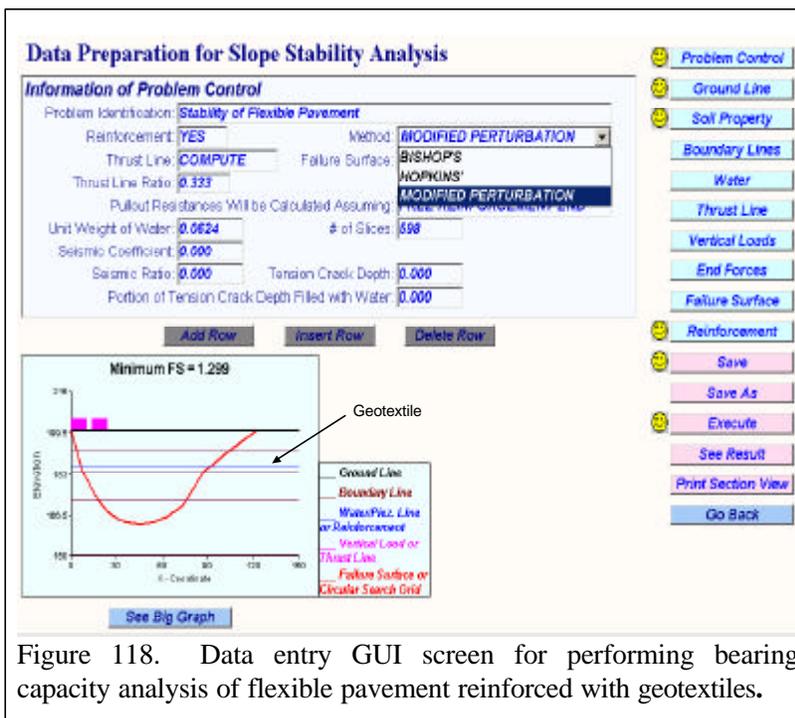


Figure 118. Data entry GUI screen for performing bearing capacity analysis of flexible pavement reinforced with geotextiles.

In the early development of the database, photographs were stored as a Bitmap file (a product of Microsoft). The file size was 2.5 Megabytes (Mb). By saving the electronic file photographs in a JPEG format, the file size was reduced to 44 Kilobytes (Kb) and reduced space requirements. Currently, there are about 5,200 photographs (of landslide and rock slope sites) in the Kentucky

Geotechnical database. An example of a series of photographs of an example rock slope was shown previously in Figure 72. By double clicking the computer mouse, an enlarged view of one of the small photographs stored in the database is obtained, as shown previously in Figure 73.

Other visual images embedded in the database include 120 county maps showing major highway routes of Kentucky. By using MapObject® software, processing speed for displaying maps is extremely fast, and maps can be displayed almost instantly. Moreover, locations and distributions of hazardous rock slope and landslides can be displayed on roadways of the embedded maps, since latitude and longitude of each site was obtained using GPS equipment. A zoom feature is included for enlarging viewing areas for details. An example of those features was shown previously in Figure 75. When a rock slope or landslide location on the map is clicked, the user is switched to detailed information, and visa versa. A limited number of digitized geological quadrangles have been embedded in the database (the Kentucky Geological Survey has a program to digitize all geological quadrangles of Kentucky and only a few of those maps are currently available). Locations of holes can be displayed on the embedded roadway maps almost instantly. The user can click on a hole location and a plot of the boring showing soil

classification (as function of depth or elevation) is graphical displayed, as illustrated in Figure 104. Merely pointing and clicking the mouse can identify any roadway on the roadway map.

Security

In developing a database involving many users, and users playing different roles in supplying different portions of the data, database security is a major issue that must be addressed because stored data can be erased, or corrupted, unknowingly by users who are not familiar with the database protocol. To maximize the security of the Kentucky Geotechnical Database, three types of systems are used. The first is called the *registered user system*. The user must be approved by the Database Administrator and registered in the database. When the user logs on, Figure 119, the system

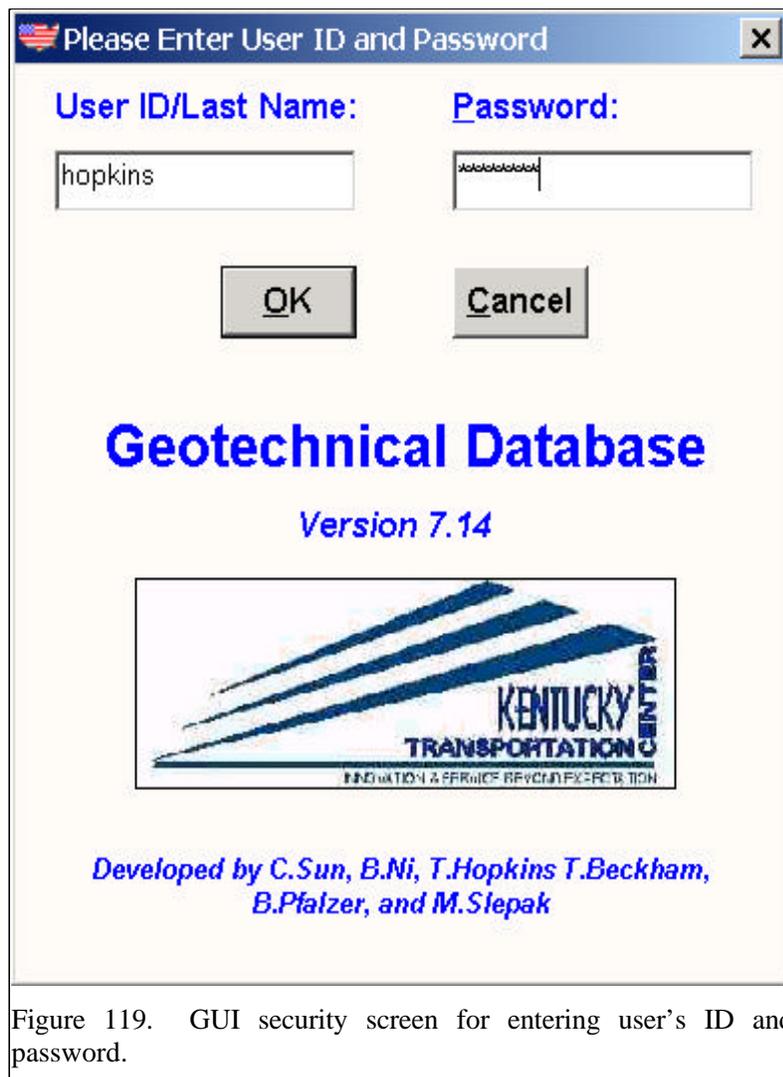


Figure 119. GUI security screen for entering user’s ID and password.

automatically checks the user's identification and password. Only after the user identification and password matches the stored values is the user allowed the privilege of logging on and connecting to the database. The second security system is called a *role-based system*. Users are divided and assigned to different groups based upon their roles in the Geotechnical Database group. Hence, a hierarchy of users is established. Titles of users in the group include Database Administrator (DBA), Officer, Data Entry, Regional Data Entry, and Viewer. The DBA has full operational functions including read, insert, update, and delete. The Officer has a full operational function but cannot delete. Data Entry Users have full (add and delete) operational functions statewide. Regional Data Entry Users have full operational functions only for sites within their own district.

The Viewer is only allowed to read and print stored data. Finally, the third security system is a recording system. Internally, the database application records and writes each operation performed by the user, such as logon and logoff times, insert, update, and delete operations. Reviewing this record, the DBA can not only trace the user's operations on the data, but also determine who is interested in the database. This feature is very valuable in tracking and locating errors in data entry, and for implementation of the database.

Engineering Units

Selection of the units for displaying engineering data is a major issue in developing an engineering database. Different users have different backgrounds and schooling, and they may find it difficult to use an unfamiliar unit system. The unit issue is also most important when different types of analyses are performed. If data were stored in the database in a mixture of both metric and English units, the user would have trouble in analyzing the data. For these reasons, all engineering data are stored in one system of units. In this case, the data is stored in Metric units. However, in the local interface, the user can switch to from Metric units to English and vice versa, as desired. This feature applies to both data entry and data retrieval.

Strategies for Data Entry, Retrieval, and Map/Graphical Displays

Data Entry

To facilitate data entry, a series of graphical user interfaces were developed, as shown previously in examples in Figures 29, 102, and 103. As noted previously, the main GUI screens contain a series of tabs near the top of the screen. For rock slopes (Figure 29), the tabs are labeled site information, total score, traffic, geometry, geologic character, climate/rock fall history, report, and picture. The GUI screen for a rock slope site contains boxes for entering such information as route number, project type, milepost markers, latitude and longitude and other site information. Values--state plane coordinates--in NAD 27 and NAD 84 are automatically calculated from stored algorithms as well as latitude and longitude. By clicking a selected tab, a data-entry GUI screen, or report, or picture(s) appears. Tabs for landslides (Figure 102) include site information, attributes and impact, history (and severity rating), maintenance costs (and activities), design and costs. When any one of these tabs is clicked, a GUI screen appears. For example, the GUI screen for attributes includes boxes for entering such information as contributing factors, utilities damaged and not damaged, average annual daily traffic and adjacent properties. Whenever possible, the "drop-down" list feature is used so the amount of typing is minimized.

The location/hole/sample GUI screen (Figure 103) contains tabs that are labeled site information, work phase, location/hole, sample, (engineering) properties, and (statistical) analyzer. When any one of those tabs is clicked, a data entry GUI screen appears. Work performed at different times at the same site is identified by work phases. Some types of

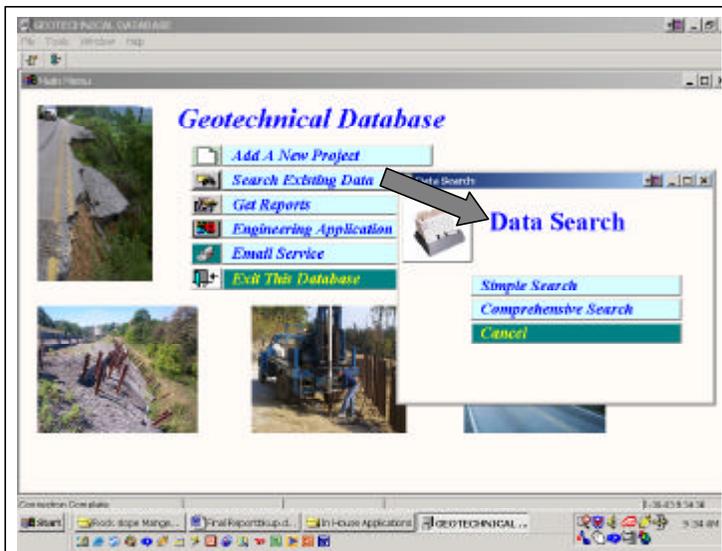


Figure 120. Types of data searches.

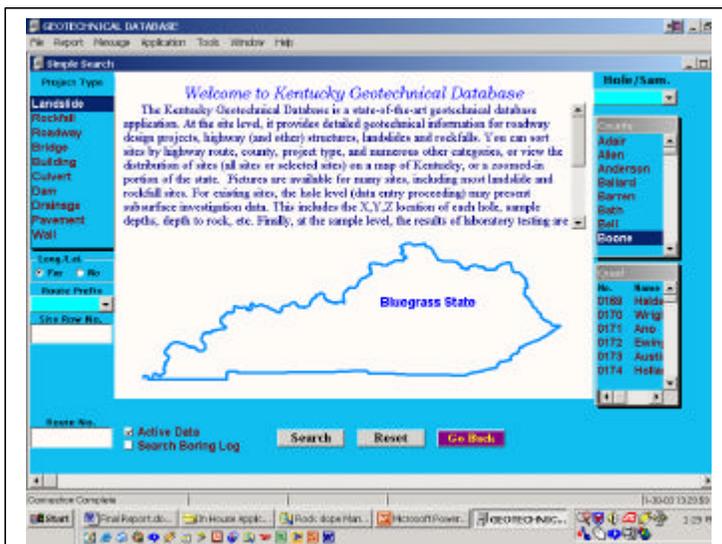


Figure 121. GUI screen for performing a simple data search.

“Simple Search” or a “Comprehensive Search.” When the simple search is executed, the GUI screen in Figure 121 appears. Different types of sites, such as landslides, or rock slopes, and their attributes may be retrieved for sites located in a selected county or geologic quadrangle, as shown in Figure 122.

The second retrieval scheme is a comprehensive search routine for amassing data. After clicking “Search Data” on the main menu (Figure 120) and “Comprehensive Search”, the GUI

information include hole number, sample type and number, elevations, work phase number, hole depth, depth to bedrock, water depth in hole, surface elevations, location accuracy of latitude and longitude, station number and offset, and USGS quadrangle number where the hole is located. When the engineering properties tab is clicked, a GUI screen is obtained, which displays a menu of soil properties, such as classification, grain size, CBR, laboratory strengths (different types of tests), field strengths (different types of tests), moisture-density tests, consolidation, visual manual descriptions, and resilient modulus test values. When an item on the menu is clicked, a GUI screen is obtained for entering the engineering data for the selected test. GUI screens for rock samples, locations, and properties can also be accessed. These screens contain such data entry boxes for hole number, type of boring, depth of bedrock, depth to the RDZ, station number and offset, sample type and number, elevations, and sampling method.

Data Retrieval Search Schemes

Different types of data retrieval schemes have been incorporated into the database, as shown in the main menu, Figure 120. In one approach, data can be retrieved using either a

Status	Ordering Number	Hwy Dist	County	Mile Posts Beg	Mile Posts End	Project Type	Site #	# of Pics	Stations (Metric) Beginning	Stations (Metric) End	Site #
U	25-0000	E	Boone	2.8	2.88	Landslide	3823	2			
U	25-0000	E	Boone	3.4	3.48	Landslide	4079	4			
U	14-0000	E	Boone	0.7	0.725	Landslide	4086	2			
U	14-0000	E	Boone	0.8	0.85	Landslide	4286	2			
U	25-0000	E	Boone	2.9	2.96	Landslide	4103	3			
U	25-0000	E	Boone	3.05	3.08	Landslide	4112	2			
U	25-0000	E	Boone	3.2	3.24	Landslide	4115	2			
U	25-0000	E	Boone	3.7	3.75	Landslide	4116	4			
U	25-0000	E	Boone	4.3	4.4	Landslide	4124	2			
U	25-0000	E	Boone	1	1.05	Landslide	4124	2			
U	16-0000	E	Boone	3.05	3.1	Landslide	4125	8			
U	336-0000	E	Boone	8	8.05	Landslide	4130	2			
U	336-0000	E	Boone	8.3	8.31	Landslide	4131	2			
U	336-0000	E	Boone	8.7	8.705	Landslide	4133	2			
U	336-0000	E	Boone	8.95	9.0	Landslide	4134	2			
U	336-0000	E	Boone	9.4	9.405	Landslide	4135	2			
U	336-0000	E	Boone	9.6	9.65	Landslide	4136	3			
U	336-0000	E	Boone	9.8	9.85	Landslide	4137	2			
U	336-0000	E	Boone	12.4	12.4	Landslide	4138	3			
U	336-0000	E	Boone	12.7	12.705	Landslide	4139	3			

Figure 122. Data retrieved from the “Simple Search” routine.

Simple Search

State: KY | Route: [dropdown] | Site Order: [] | Project Type: [] | Highway District: [] | County: [] | Beg. Mp: []

Date: [] | Class: [] | Score: [] | USGS Map: [] | Depth To Bedrock: []

Comprehensive Search

Table	Column	Operator	Value

Buttons: OK, Cancel, Reset

Figure 123. Comprehensive search GUI screen.

screen shown in Figure 123 appears. This system uses a system of operators such as equal to, or greater than, less than, etc. Using this retrieval method, the user may construct any type of report. In this scheme the user may use a simple “comprehensive” search routine involving a limited number of prefixed parameters and operators or the user may use a comprehensive scheme using any number of selected parameters.

For instance, in the example shown in Figure 124, the user wanted a listing of all landslides on the Mountain Parkway in Kentucky that were located at or greater than mile point 33.6 and that have occurred before April 10, 2003. After clicking on the “Search Existing Data” and “Comprehensive Search, in the upper portion of Figure 124, and clicking the button, “Simple Search” (on the Comprehensive Screen) the screen in the lower portion of the Figure appears. Using a dropdown list of routes, the user clicks “MT”, uses the operator, >=, inserts 33.6 into the “Beg.MP” box, and uses the operator, <or =, and inserts the date, 04/10, 2003. Clicking

okay, the data illustrated in Figure 125 appears. By double clicking on a selected landslide site, (highlighted at the right), the GUI screen at the lower portion of the screen appears. This screen displays a number of tabs, labeled “Site, Attributes and Input, History, Maintenance Cost, Design and Cost, and Pictures”. Clicking any one of those tabs will display detailed information.

The comprehensive data search is illustrated in Figure 126. In the latter approach, the user may add as many database parameters and operators as desired to build the data search. In the example, the user is retrieving rock slopes that were rated (RHRS score) 650 but less than 670. In this case, two operators, > or = and <, were used to retrieve the data report schemes.

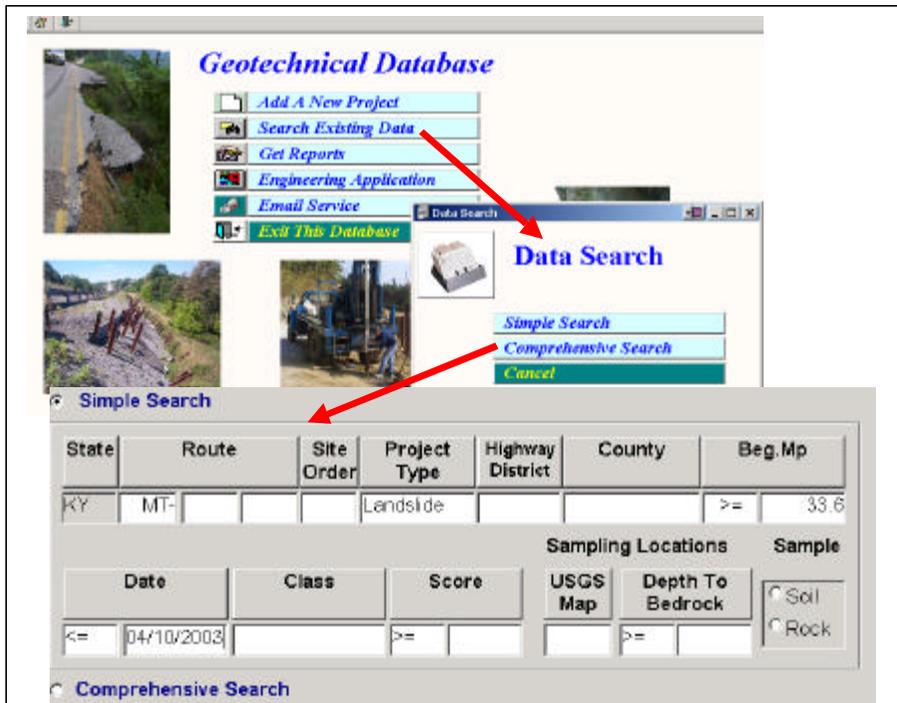


Figure 124. Method for performing a comprehensive (“simple”) data search.

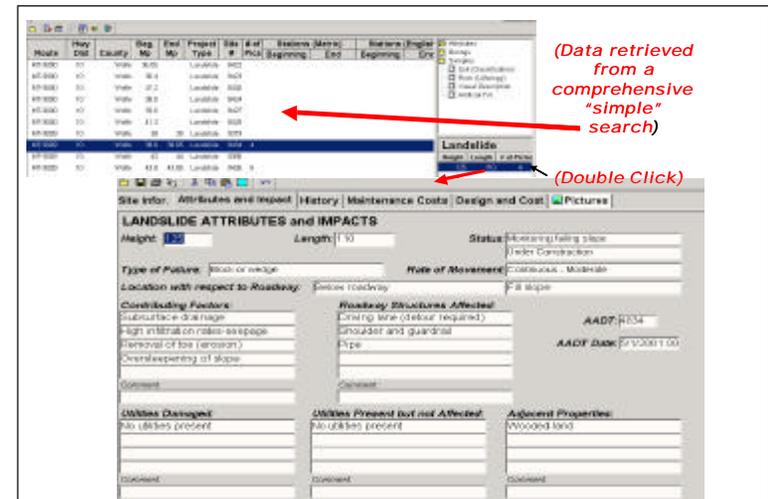


Figure 125. Retrieved data using the comprehensive “simple” search routine.

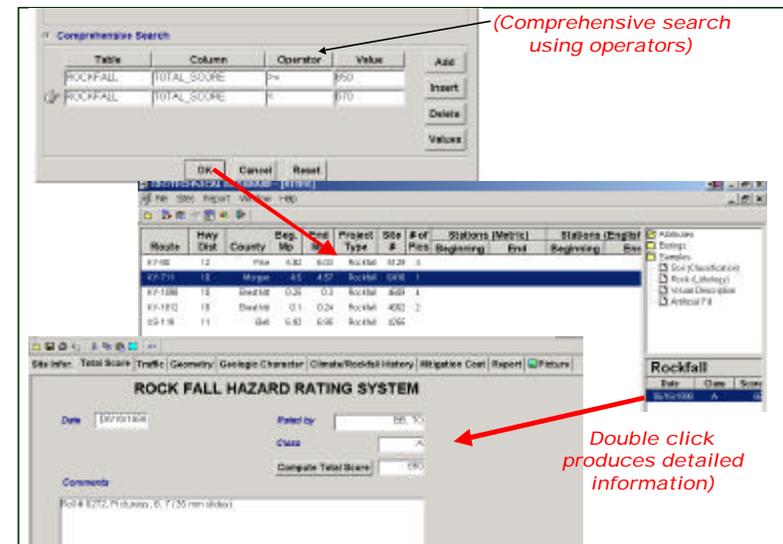


Figure 126. Comprehensive search using operators.

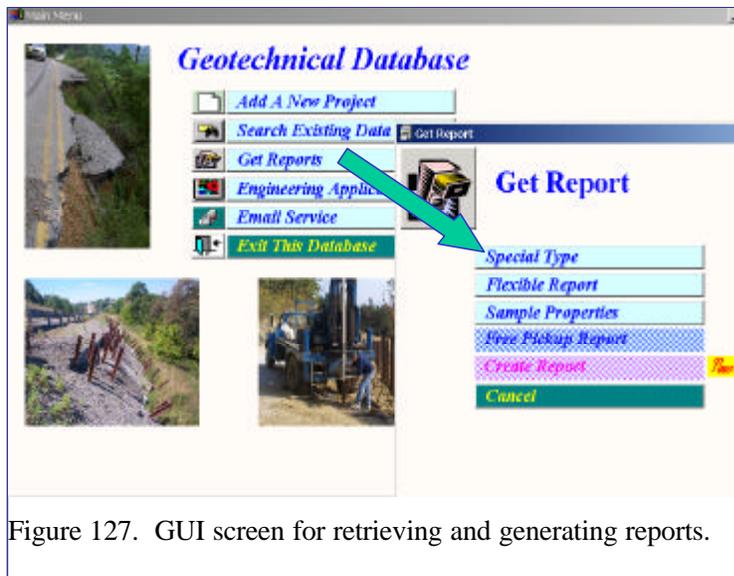


Figure 127. GUI screen for retrieving and generating reports.

Data report Schemes

In addition to the simple and comprehensive search features, another scheme has been included in the database for retrieving and generating data reports. When the “Get Reports” button on the main menu is clicked, the GUI screen shown in figure 127 appears. Presently, the user has three choices for generating reports. These are titled “Special,” “Flexible,” and “Sample Properties”. Other reports shown on the menu are under construction.

When the “Special” report button is clicked, the GUI screen in Figure 128 appears. Clicking on the “selection” button displays several choices: Counties, Route number, Highway District, Report Type (refers to reports issued by the Geotechnical Branch, Division of Materials, of the Kentucky Transportation Cabinet). This scheme allows the user to construct many different types of listing and combinations of various parameters. For instance, if the “Report Type” is clicked, then the listing, “B, L, M, R, and S,” appears in the right-hand side of the GUI screen (Figure 128). Clicking, for example on “R” (rock fall reports), produces the listing of

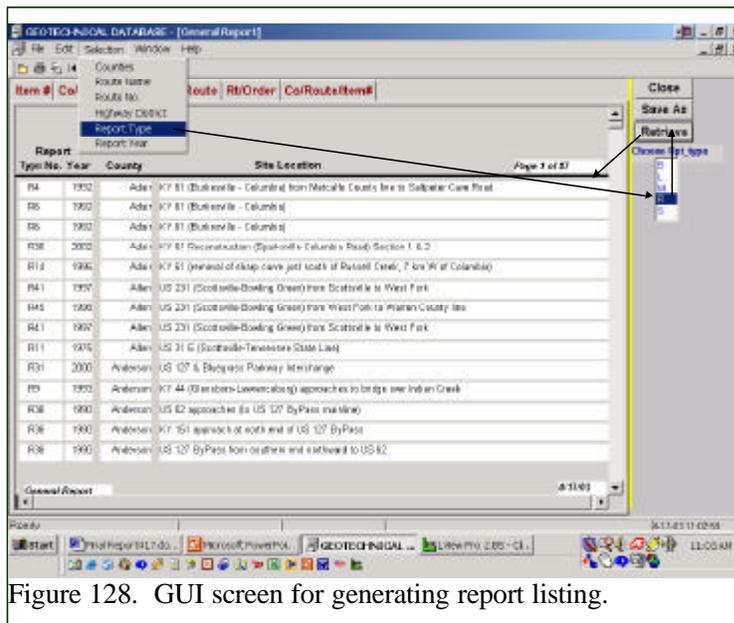


Figure 128. GUI screen for generating report listing.

reports in the central portion of the GUI screen.

In the second type of report generator, data can be filtered to obtain the desired data. Although the parameters used for filtering are preset, a great deal of flexibility has been programmed into the filtering process. The database contains three preset filtering retrieval schemes. Soil and rock data and other attributes pertaining to landslides, roadways, rock slopes, SCS (Soil Conservation Service), and structures may be retrieved to generate reports. When the landslide button is clicked, the GUI format shown in Figure 129 appears. In this format the user may select a particular highway district², or a combination of highway districts, or “All” highway districts, route, the class of landslide (A, B, C, D)³, landslide data collected by the Kentucky

² There are twelve highway districts in Kentucky under the jurisdiction of the Kentucky Transportation Cabinet.

³ Severity Classes of landslides described in previous section entitled “Landslide Data and Management System,” page 51.

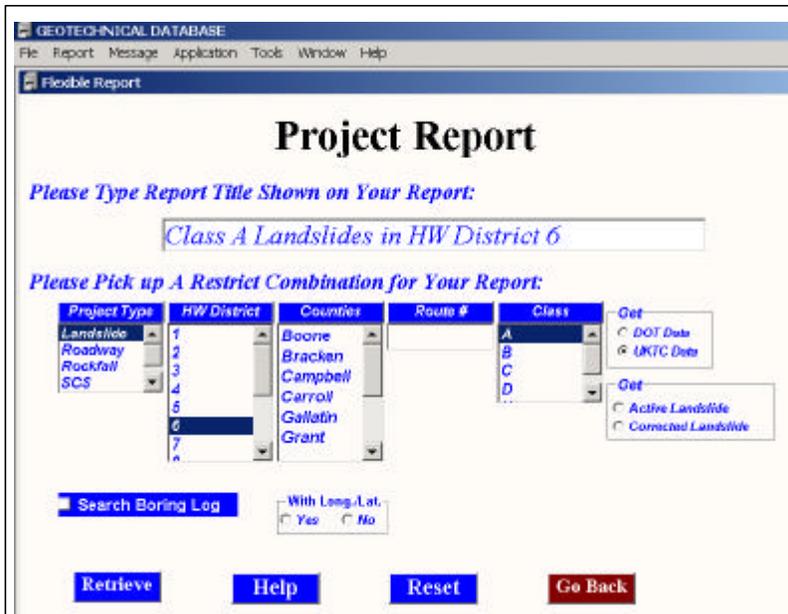


Figure 129. GUI format for filtering and generating a landslide report for a specific area (highway district or county), route(s), and class of landslide.

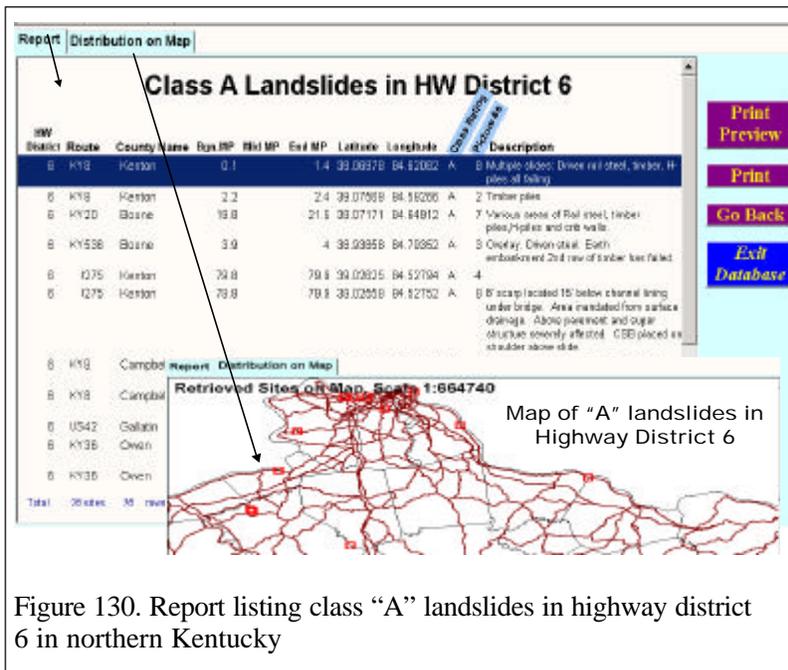


Figure 130. Report listing class “A” landslides in highway district 6 in northern Kentucky

Transportation Cabinet (KYTC), or the University of Kentucky Transportation Center (UKTC), active or corrected landslides, boring log, latitude and longitude.

An example of using the flexible report procedure for compiling a landslide report is shown in Figure 129. In this example, the user is interested in obtaining a listing of active landslides rated “A” (very serious) in Highway District 6 in the northern portion of Kentucky. The user clicks “Landslide”, “HW District” 6, Class “A” and punches the buttons “UKTC Data”, “Active”, and “With Long/Lat”.

When highway district 6 is clicked, the counties in that district automatically are listed. The report is given a title as shown in Figure 129. After punching the “Retrieve” button, the GUI listing appears as shown in Figure 130. The data shows that there are a total of 16 landslides in Highway District 6 rated “A”. As of the date of this report, about 370 landslides have been identified in Highway District 6 that are rated “A” and “B”(very serious and serious, respectively). A total of about 545 landslides were identified in the district. A map of the “A” landslides may be obtained by clicking on “Distribution on Map”. By highlighting and clicking on a site, the GUI shown in Figure 131 appears giving detailed information. Photographs of the site may be viewed by clicking “Pictures”.

By clicking “Roadway” in Figure 132, the user may retrieve hole data. In this example, the user wishes to retrieve hole data with latitudes and longitudes in Highway district 1. The user

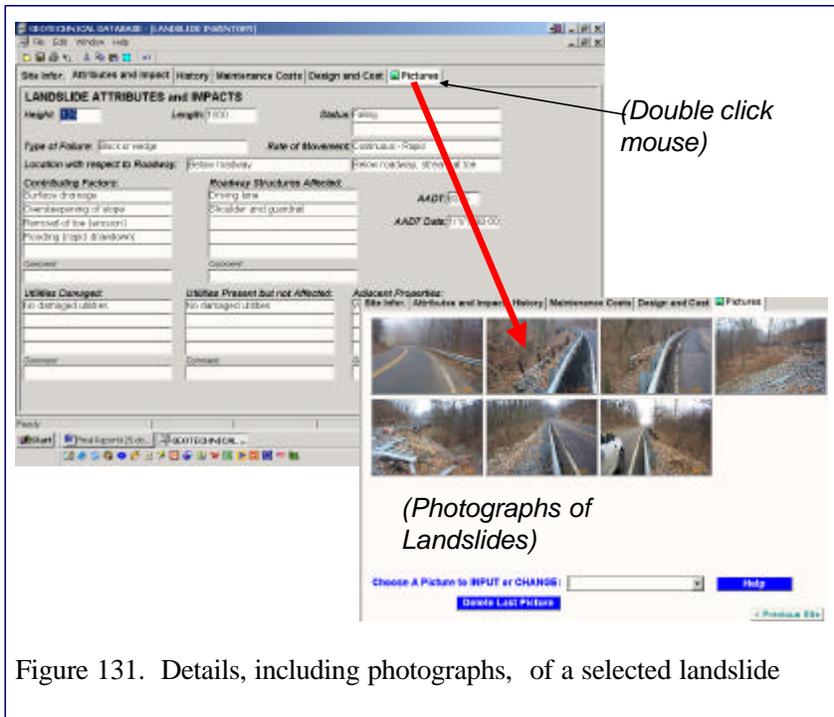


Figure 131. Details, including photographs, of a selected landslide

clicks “Roadway”, “HW District” 1, “Holes”, and “With “Long./Lat”. The listing appears as shown in Figure 133. By clicking on “Distribution on Map”, view of the holes on a map of the western portion of Kentucky appears. The user may use a zoom feature to get closer views of the plotted holes.

Another example of using the filtering process is illustrated in Figure 134. In this example, potentially hazardous rock fall sites on interstate 75 in Kentucky having a numerical rating equal to or greater than 350 is sought. The report that is

generated is illustrated in Figure 135. . By clicking on any heading, the data are sorted (ascending or descending) according to the selected heading. For instance, by clicking on the heading, “ total score” the user can arrange the data in ascending numerical scores. Moving the cursor to any selected site (highlighted) and double clicking takes the user to detailed information of the rock fall site. By clicking on “see Map” the rock fall sites on Interstate 75, having numerical ratings of 350 or greater, are displayed on a roadway map of Kentucky (lower right-hand portion of the figure).

As shown in Figure 136, soil and rock data properties in the database may be retrieved using the “Sample Properties” of the main menu. For example, if “Classification” on the menu is clicked, then classification data of all stored data is retrieved as shown in Figure 137. Tables of other sample properties, such as gradation, CBR, lab and field strengths, consolidation, visual descriptions, slake durability, and rock quality designation (RQD), may be obtained.

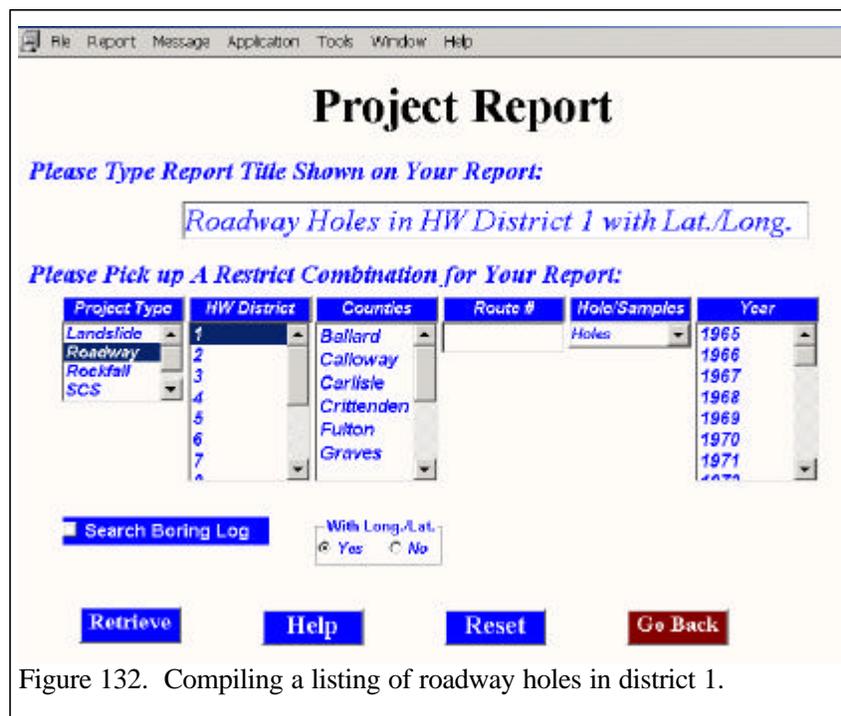


Figure 132. Compiling a listing of roadway holes in district 1.

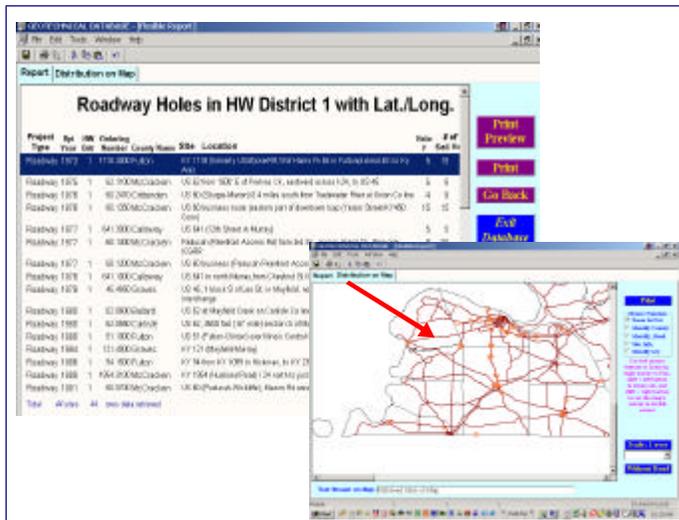


Figure 133. Listing of holes in Highway District 1 with latitudes and longitudes.

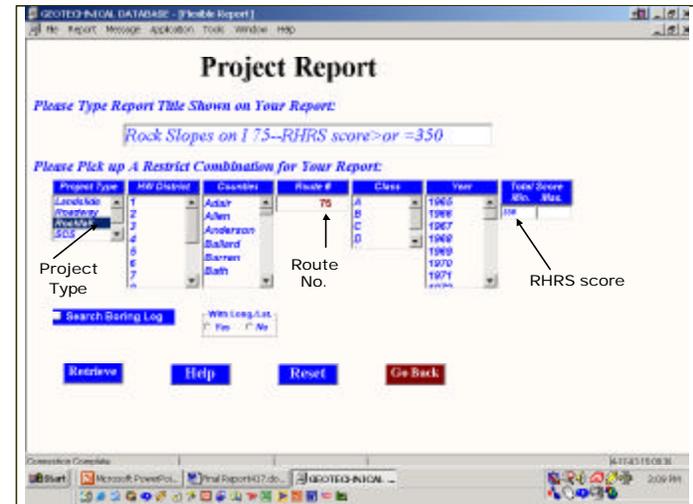


Figure 134. Compiling a listing of rock slopes on I 75 with RHRS scores greater than or equal 350.

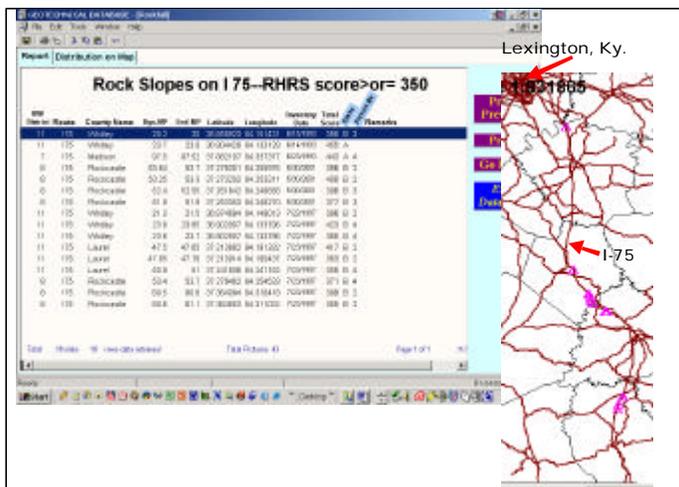


Figure 135. Listing of rock slopes on I 75 with RHRS scores greater than or equal to 350.

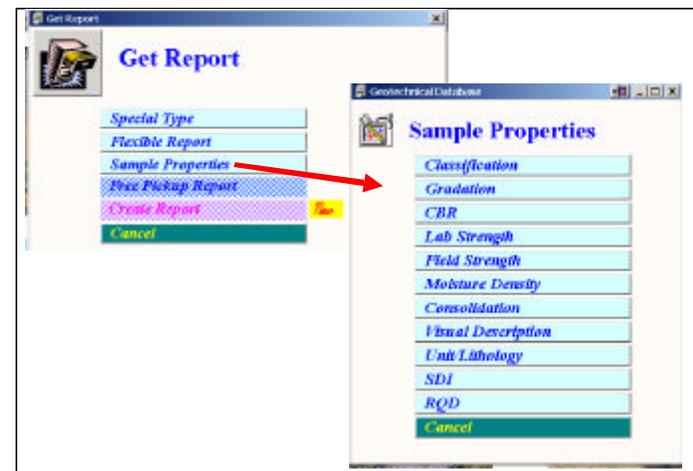


Figure 136. Method of retrieving soil properties of all stored data in the database

Classification Table Detail

Hole Id	Sample Id	Depth To Top To Bot.	AASHTO	Unified	N	SPG	LL	PI	NMC	d50 Shrinkage L
Site Location: US 45 (Mayfield-Paducah) over Mayfield Creek Overflow										
1	1	1.524 2.1336							32.1	
	2	3.048 3.6576							29.2	
	3	4.4160 4.8768			33					
	4	5.9436 6.4008			43					
	5	7.4676 7.9248			57					
	6	8.8868 9.4488			47					
2	1	1.524 2.1336								
	3	4.4160 4.8768	A-2-4(0)	SW-SM	40	2.64				
	4	5.9436 6.4008			37					
	5	7.4676 7.9248			41					
	6	8.8868 9.4488			78					
	7	10.5156 10.9728			33					
3	8	12.0306 12.4888			43					
	9	15.8824 16.288	A-8(20)	CL		2.64	38	18		
	1	1.524 2.1336								
	2	3.048 3.6576								
	4	5.9436 6.4008			22					
	5	7.4676 7.9248	A-2-4(0)	SM	43	2.64				
6	8.8868 9.4488			53						
7	10.5156 10.9728			32						

Page 7 of 7302 Total rows retrieved: 21564 Report on: 4/29/2003

Figure 137. Listing of classification data.

SUMMARY AND CONCLUSIONS

As a means of establishing a comprehensive system for managing rock slope (and landslide) problems in Kentucky, a geotechnical database was developed and is described herein. Developing a geotechnical database in a client /server and windows environment facilitates and provides efficient means of entering and retrieving geotechnical data. Development tools included Oracle® 7.3 and PowerBuilder® 6.0 and 7.0 software. The database was partitioned into major and secondary components. Major parts of the database consist of rock slope, landslide, structures, and soil and rock engineering data. Programmed procedures of the database are used by the Kentucky Transportation Cabinet to identify hazardous conditions and for risk management of landslides and rock slopes. Procedures for entering and retrieving historical soil and rock engineering data have been developed. Procedures for retrieving soil and rock data, as it is generated, are under development. Methods of analyzing data statistically while connected to the database were developed for user convenience. Also, design applications, such as pavement design, or retaining wall design, have been developed and are included in the database as a convenience to users and to improve efficiency. Other applications are under development. Three procedures for safeguarding use of the database are described. Engineering units are stored using one system of units, but conversions from one system to another can be made on screen at any time. Saving and storing electronic photographs using JPEG software minimized storage requirements and, yet, did not sacrifice picture quality. File size of each photograph was only about 44 Kilobytes. MapObjects® software provided a good means for displaying quickly roadway maps and overlays of locations of landslide, rock slope, and boring locations. This report focused on building a system for managing rock slope problems.

The actual numbers of potentially hazardous rock slopes existing on highways under the jurisdiction of the Kentucky Transportation Cabinet were unknown prior to this study. This report and the inventories of rock slopes performed on Kentucky's highways and described herein is a response to a suggestion by FHWA. These efforts represent the first major step in attempting to correct and rock fall problems in Kentucky. To develop an effective management plan requires identifying and developing information of rock slope sites where future corrections and reconstruction may be needed to improve safety and to maintain, or, increase the traffic capacities of roadways. The main focus of this study and report was developing an inventory of highway rock slope problems occurring on Kentucky's highways and a rock slope management database system. Inventory data is stored on a server of the Kentucky Transportation Cabinet. All twelve Highway District Offices and several Central Offices (in Frankfort) of the Kentucky Transportation Cabinet are connected to the database and server. Hence, the data is readily accessible.

Based on the inventory highway rock slopes in Kentucky, the following observations are offered:

- ?? Grouping rock slopes into preliminary (subjective) categories, "A", "B", or "C" appears to be a reasonable approach. An "A" slope is considered by the rater to be potentially hazardous, while a "C" is considered to pose no danger. In placing a slope into a "B" category, the user is not sure about the potential danger of the slope. In analyzing the numerical ratings obtained from the RHR System, the rock slopes identified as "A" had a mean numerical score of 478. At one standard deviation, the scores ranged from 388 to 568. The mean score of the rock slope identified as "B" was 321 and at one standard deviation the score ranged from 224 to 418.
- ?? RHRS scores of "A" and "B" rock slopes in Kentucky ranged from a low of 69 to 689. The maximum score in the RHRS approach is 900. Numerical scores of "A" slopes ranged from 241 to 689. The range for the "B" rated slopes was 69 to 562.
- ?? The height of approximately 26 percent--about 560 rock slopes--of the surveyed slopes ranged from 100 to 368 feet. As the height of slope increased the RHRS score increased. As the height of slope increases, the mitigation, or repair costs increase. The mean RHRS score of those slopes was 410.
- ?? In about 43 percent of the surveyed cases the "ditch effectiveness" was adequate to "good". However, in about 1 slope in 5 slopes, the ditch effectiveness was very "limited" to "no ditch". In those cases, potential traffic hazards exist, since any rock fall that may occur will land in the roadway.
- ?? In about 1 slope in 4 slopes, the average vehicle risk, AVR, was significantly large and the chance that a vehicle may be hit by falling rock in those cases was very large. To prevent rock fall from entering the highway, sufficient space between the toe of the slope and the pavement, or "ditch effectiveness," was scored.
- ?? At about 1 in 3 slopes, the percent of decision sight distance was "limited" to "very limited". Hence, at those sites, if rock fall reaches the pavement, a driver would have very little time to respond to the roadway rock.
- ?? In 67 percent of the observed cases, rock jointing scored higher than differential erosion. However, both factors were significant in causing rock fall. At sites containing vertical cuts and hard and soft geologic units exposed in the cut face, differential erosion was oftentimes very severe. In cases of this

- type, the slope must be stepped or/and designed following criteria similar to those proposed by Ritchie (1963).
- ?? In about 3 of 5 slopes, the block size that potentially could fall (or was actually observed at a site) was large and ranged from about 3 ft to 41 feet. In about 2 of 5 rock slopes, the volume size (potential or observed rock fall) the volume size ranged from 9 to 24 ft³.
 - ?? In about 38 percent of the observed cases, the roadway score to avoid rocks that may reach the paved roadway was large which meant that roadway width did not offer much maneuverability.
 - ?? Rock fall history was described as “Many” to “Constant” at slopes that scored larger than 500 using the RHRS method. For slopes scoring in the range of 300 to 500, the rock fall was described as “Occasional” to “Many”.
 - ?? As shown by a limited number of examples cited herein, the cost of repairing, or applying mitigation measures, can be large. Remedial measures for a site may range from a few thousands of dollars to amounts exceeding several million dollars. Although the exact money needed to repair the large number of rock slopes identified herein and stored in the database is unknown at this time, the amount is believed to be very large and may well exceed several hundred million dollars.
 - ?? In an attempt to establish a linkage between the RHRS score and rock fall history, it is strongly recommended that the Kentucky Geotechnical Database be fully implemented. This means that state personnel should start entering data into the system. When rock fall does occur at sites identified during this study, or new sites, the data should be entered describing the event, date, costs, and other important data pertaining to the event. By entering data each time an event occurs, this will aid in further identifying sites that pose dangers to the traveling public and help in establishing a priority list for future repairs. Hence, entering rock fall events history at each site by field personnel is essential to developing experience with the RHRS approach and improving the rating system in the future. In essence, by entering data, the system can provide an effective means of managing rock slope and landslide problems.
 - ?? To achieve maximum benefits of the management system proposed herein, it is recommended that the rock slope and landslide portions of the database be fully implemented. This means that district engineers, operations’ engineers and personnel, and geotechnical engineers start entering essential data into the Kentucky Geotechnical Database. For instance, when a rock fall occurs at a site, field personnel need to enter this fact and include the cost of cleanup, any road closures, fatalities, or injuries, date of occurrence, and any other pertinent information. When any type of maintenance, or remedial mitigation, is performed at a site, this information should be added to the database. Similarly, when maintenance is performed at a landslide site, this information should be added to the database. For example, if rail piles have been added to the site, then this information, including costs and date of repairs should be added to the database. When a roadway is patched, the date and cost should be entered into the database. Patching a roadway in a landslide area more than 2 or 3 times may indicate that the landslide is continuing to move. By

implementing the rock slope and landslide management systems, that is, daily or weekly entering rock fall events history at each site by field personnel experience with the RHRS approach can be gained and improvements in the rating system can be made in the future.

In addition to fully implementing the management systems built into the database, the next phase of addressing rock slope and landslide problems may involve development of preliminary plans so that cost estimates may be made. Basically, the first step in this process will involve obtaining cross sections of the slopes so that rock fall analyses may be performed. In estimating the type of remedial plan, or mitigation measure(s), to apply at a selected site, it is recommended that the Colorado Rock Fall Simulation program be used, when appropriate. In obtaining preliminary cross sections for performing the rock fall computer simulation calculations, it is recommended that new laser technology be considered. At least two approaches are available. In the first approach, a “laser” gun may be attached to a GPS unit and used to obtain an “open-face” geological log and profile of the rock slope. The user can usually position the laser gun and GPS unit at one location and point the laser at geological boundaries on the slope. A profile(s) of a slope may be obtained quickly using this approach. In certain instances, the profile may have to be obtained when foliage is not present. In the second approach, new 3-dimensional laser technology can be used to scan, or map, the entire slope in a reasonable time. After scanning, individual (2 dimensional) cross sections may be obtained for analysis. After obtaining a profile, the rock fall computer simulation runs would be performed to estimate the best remedial scheme and costs. Cross sections of the rock slope, computer results, and estimated repair methods and costs can be stored in the Kentucky Geotechnical Database for future reference. . In the second approach, new 3-dimensional laser technology can be used to scan, or map, the entire slope in a reasonable time. After scanning, individual (2- dimensional) cross sections may be obtained for analysis. After obtaining a profile, the rock fall computer simulation runs would be performed to estimate the best remedial scheme and costs. Cross sections of the rock slope, computer results, and estimated repair methods and costs can be stored in the Kentucky Geotechnical Database for future reference. Considering the large numbers of potentially hazardous rock slopes and landslides identified in the inventories, and the large costs normally involved in repairing a single landslide, or rock slope problem, several millions of dollars will be required to correct those problems.

RECOMMENDATIONS

It is strongly recommended that the rock slope management system proposed herein be immediately adopted by the Kentucky Transportation Cabinet and every effort should be made to implement the use of the management system. To effectively use the management system, is essential that highway personnel begin to populate the database with field information. Specifically, when rock fall occurs at any site, highway personnel should immediately enter this information into the database. An estimate of the size and volume of rock fall (or debris flow) and date of occurrence should be entered into the system. When any type of maintenance is performed at a rock slope site, the type of maintenance and estimated (or actual cost) cost of the work should be entered into the database. If a rock slope site is not in the database, then personnel should create a new site in the database. By populating the database with up-to-date information, adjustments and refinements in the ratings of the rock slopes can be made.

Attributes of the site should be noted and the hazardous nature of the site should be rated using the Oregon/FHWA Hazardous Rockfall Rating System. After a trial period of using the system, it may be necessary to make adjustments and modifications in the database structure. It should be recognized that it was not feasible to catalog all hazardous rock slopes on Kentucky's highways because UKTC researchers could not be aware of all hazardous slopes. Consequently, it is essential that field personnel, who may have the best knowledge of a potentially hazardous site, identify sites not listed in the database.

Identifying the numerous and potentially hazardous rock slopes on Kentucky's highway and constructing a database management system represents the first stage in addressing this problem. The management and rating system provides a means of developing a priority list of sites that may need repairs or the application of remedial measures. The second stage will involve developing engineering remedial, or mitigation, plans and cost estimates. This information can be stored in the database. It is recommended that a research study be initiated to explore ways of obtaining, rapidly, rock slope cross sections for engineering analysis. Specifically, the use of two- and three dimensional laser technology should be examined as a fast means of obtaining cross sections and open-face geological logs of rock slope problem sites. These data could be stored in the database for future analysis. By storing the Colorado Rock Fall Computer Simulation software in the database, rock slope analysis and design could be performed via of the database. Consequently, results of the analysis would be available for review and discussion by engineers and administrators who have an interest in the rock slope problem sites.

Finally, considering the sheer number of potentially, hazardous rock slopes identified in this study (about 2,400) and that many of those rock slopes were partially financed by federal funds originally, federal participation in future funding of repairs, or mitigation measures, should be requested by the Kentucky Transportation Cabinet. It is estimated that rock slope repairs or mitigation measures will cost hundreds of million of dollars and may be beyond the scope of expenditures that the state could earmark for this problem. Hence, it is recommended that a special federal highway fund be established to address the rock slope problems not only in Kentucky but also for all states that have severe rock slope problems.

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